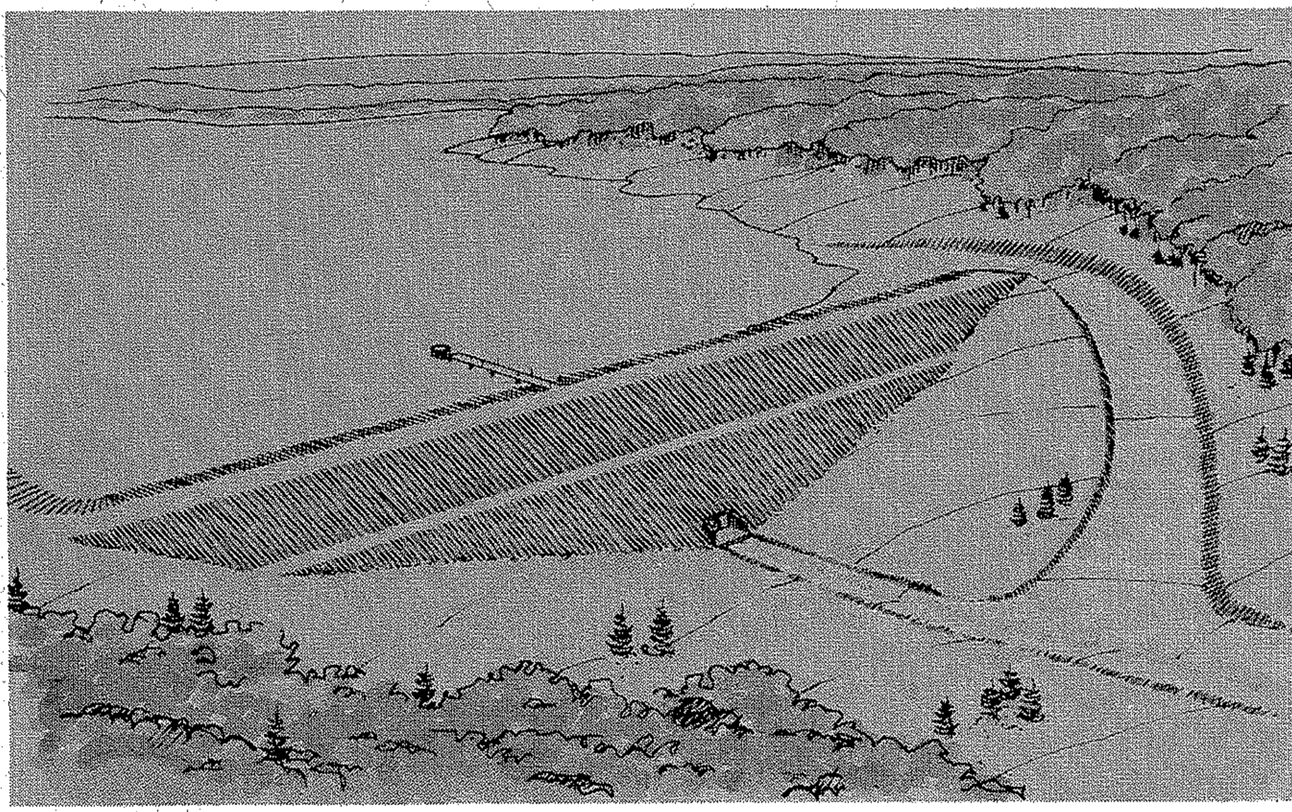

Dam Safety Guidelines

Technical Note 3:
Design Storm Construction

WASHINGTON STATE
DEPARTMENT OF
ECOLOGY

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Technical Note 3:

Design Storm Construction

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DESIGN STORM CONSTRUCTION

OVERVIEW

This Technical Note provides engineering guidance for development of design storms for use in computing Inflow Design Floods (IDFs) using rainfall-runoff computer models. It is a companion document to Technical Note 2, *Selection of Design/Performance Goals for Critical Project Elements*[1], and to Chapter 2.4 of *Part IV* of the *Dam Safety Guidelines* on the computation of Inflow Design Floods.

It presents a number of probabilistic based procedures which incorporate findings from recent studies of historical extreme storms in the Northwest. In particular, it incorporates design/performance goals from Technical Note 2, with findings from the *Regional Analyses of Precipitation Annual Maxima in Washington State*[2] for computation of site specific precipitation magnitude-frequency characteristics. It also utilizes information from Ecology report 89-51 on the *Characteristics of Extreme Precipitation Events in Washington State*[3] for development of probabilistic hyetographs for candidate design storms.

Efforts have been made to present the probabilistic application procedures in a straightforward, useable manner without the extensive theoretical and mathematical background which often accompanies probabilistic methods. Readers are directed to the referenced journal articles and research documents for any additional mathematical background which is deemed necessary.

Research continues in the area of extreme storms on a number of levels. This technical note will be updated from time to time as advances are made in the understanding of extreme storms and as improvements are made in technologies and methodologies for analysis of extreme storms and in procedures for design usage.

DESIGN STORM CONSTRUCTION

1. INTRODUCTION

The development of candidate design storms is a key step in the process of developing a rainfall-runoff computer model for computation of an Inflow Design Flood (IDF). In particular, the precipitation magnitude and temporal distribution of a storm are usually dominant factors in determining the magnitude of the resultant flood.

If a project under design/evaluation has a small reservoir relative to the size of the contributing watershed, then flood peak discharge will normally be the controlling consideration. Thus, precipitation intensity will usually be the primary consideration in developing the design storm. In contrast, if the reservoir is very large relative to the size of the contributing watershed, then runoff volume will be the controlling factor. In this case, the total volume of precipitation is the primary consideration. For most real world situations, projects are sensitive to various combinations of flood peak discharge and runoff volume and thus, both precipitation intensity and volume must be considered in developing design storms.

In the Northwest, considerations of precipitation volume and intensity are further complicated by seasonal effects which must be accounted for in rainfall-runoff modeling. Short duration thunderstorms, which can contain very high precipitation intensities, are warm season events. Conversely, the long duration general storm events occur primarily in the winter months and are characterized by large precipitation volumes but relatively moderate and uniform intensities. To accommodate these meteorologic characteristics, it is normally necessary to develop several candidate design storms, representing various storm durations, intensities and volumes, to allow a determination of the controlling event for design/evaluation of spillway size and hydraulic adequacy.

This technical note is intended to provide engineering guidance in developing candidate design storms which reflect the diversity of storm duration, intensity and volume which are found in the Northwest. A worksheet is contained in Appendix B for use in computing precipitation magnitude-frequency curves and for determining the precipitation amounts to be used for constructing design storms.

1.1 TERMINOLOGY

A variety of terms are needed to describe the characteristics of design storms. The following selected terms are defined to clarify their meaning for use in this technical note and to provide a common definition for use in *Part IV of the Dam Safety Guidelines* regarding *Dam Design and Construction.*

Annual Exceedance Probability (AEP) - The chance that a specified magnitude of some phenomenon of interest is equaled or exceeded during a given year.

For example, in Olympia, WA., a 24 hour precipitation depth of 5.5 inches has an AEP of 0.01. Stated another way, there is one chance in one hundred that 5.5 inches of precipitation or more will fall in Olympia in some 24 hour period in any given year.

At-Site - Refers to site-specific characteristics as distinguished from regional characteristics. When used in the context of regional analyses, it refers to precipitation characteristics at a specific measurement recording station or geographic location of interest.

Candidate Design Storm - A hyetograph which is used in rainfall-runoff modeling to determine the flood response of a watershed and the response of a project's reservoir and spillways. The candidate design storm which produces the most stringent loading condition for a project's reservoir and spillway(s) is deemed the Design Storm.

Depth-Duration Curve - A precipitation mass curve constructed in a manner whereby the largest incremental precipitation amounts are located at the start of the mass curve and progressively smaller amounts are accumulated to produce the remainder of the curve (see also reference 3).

Design Step - An integer value from one through eight which is used as an index for increasingly stringent design/performance goals. The design step is used herein and in *Part IV* of the *Dam Safety Guidelines* to set design events and loading conditions for design or evaluation of critical project elements such as spillways.

Design Storm - The hyetograph, depicting the precipitation volume, intensities and duration, which is to be used in rainfall-runoff modeling to generate the Inflow Design Flood for design/evaluation of the hydraulic adequacy of a project.

General Storm - A generic term for precipitation produced over large areas by synoptic scale weather features such as cyclones and associated fronts.

Hyetograph - A graphical representation of precipitation as it occurs with time. It may be for a specific location or represent an average over a specified area. It may be discretized or continuous over time, displaying either incremental or accumulated precipitation.

Intensity Index - A dimensionless measure of the precipitation intensity used with dimensionless design hyetographs to graphically characterize the precipitation intensity. Actual intensities are obtained by multiplying the intensity index values by the applicable value of the 2 hour, 6 hour or 24 hour design precipitation depth for the short, intermediate and long duration design storms respectively.

Intermediate Duration Precipitation Event - A precipitation event which occurs over a period from 6 to 18 hours. When used in the context of a design storm, this term refers to 18 hour events which are characterized by high rainfall intensities, contain a large total precipitation volume and generally occur in the fall and early winter seasons.

Large Watershed - For purposes of this technical note, a large watershed is defined as being sufficiently large that the spatial distribution of the storm over the watershed must be accounted for explicitly. This corresponds to watersheds which exceed 10 mi^2 when a long duration or intermediate duration storm is the design event, and watersheds larger than 1 mi^2 when a short duration thunderstorm is the design event.

Local Storm - A storm comprised of an isolated convective cell or group of cells, commonly referred to as a *Thunderstorm*. Its occurrence is unrelated to any precipitation producing synoptic weather feature such as a cyclone or associated front. These storms can produced very high precipitation intensities over localized areas.

Long Duration Precipitation Event - A precipitation event which occurs over a period from 24 to 72 hours. When used in the context of a design storm, this term refers to 72 hour events which are characterized by relatively moderate and uniform intensities, contain a very large total volume and generally occur in the winter season.

Orographic Precipitation - Precipitation which occurs from lifting of atmospheric moisture over mountain barriers.

Precipitation Magnitude-Frequency Curve - A graphical description of the relationship between precipitation magnitude (depth or volume) and annual exceedance probability.

Precipitation Depth - The amount of precipitation, expressed in inches or millimeters, which would collect in a standard measuring device. It is synonymous with point rainfall.

Precipitation Intensity - The rate of precipitation expressed in inches/hour or millimeters/hour.

Precipitation Depth - The amount of precipitation, expressed in inches or millimeters, which represents the average precipitation over some specified area, such as a watershed of interest.

Probable Maximum Precipitation (PMP) - Theoretically, the greatest depth of precipitation for a given duration that is physically possible over a given size storm area at a particular geographical location at a certain time of the year (National Weather Service[4] definition).

Short Duration Precipitation Event - A precipitation event which occurs over a period from 1 to 6 hours. When used in the context of a design storm, this term refers to thunderstorm events in the warm season which are characterized by very high rainfall intensities, often with limited total volume occurring over isolated areas.

Small Watershed - For purposes of this technical note, a small watershed is defined as being sufficiently small that the spatial distribution of the storm over the watershed is not significant. This corresponds to watersheds smaller than 10 mi^2 when a long duration or intermediate duration storm is the design event, and watersheds smaller than 1 mi^2 when a short duration thunderstorm is the design event.

1.2 GENERAL GUIDANCE IN APPLICATION OF CANDIDATE DESIGN STORMS

The following general guidance is provided in application of candidate design storms for the design/evaluation of spillway size, hydraulic adequacy and/or reservoir floodwater storage capacity. This guidance is based on past experience in rainfall-runoff modeling using the design storm procedures described here. However, this does not preclude the user from investigating the flood response from other candidate design storms as deemed necessary to determine the controlling event.

1.2.1 Western Washington

Long duration storms are commonly the controlling design events in western Washington. This is particularly the case when the reservoir has a relatively large storage volume relative to the runoff producing capability of the tributary watershed. It is always the design event for off-channel storage reservoirs where there is minimal watershed area tributary to the reservoir.

Projects with small storage capacity relative to the runoff producing capacity of the tributary watershed are sensitive to flood peak discharge. In these situations, the higher intensities in intermediate duration storms may become the controlling consideration, particularity in coastal areas.

Short duration thunderstorm events usually do not produce sufficient runoff volume to be the controlling event for project spillways. The possible exception is the case of large stormwater detention facilities in urban areas. In this situation, there may be a high percentage of impervious area which could make the peak discharge from a short duration event the controlling consideration.

1.2.2 Eastern Washington

The short duration thunderstorm is commonly the controlling design event in eastern Washington when the tributary watershed is less than about 50 mi^2. The very high intensities in these storms can produce very large flood peak discharges which often becomes the dominant consideration in sizing the spillway(s).

The long duration event is usually the controlling design event when the tributary watershed is very large or when the reservoir storage capacity is large relative to the runoff producing capability of the tributary watershed. The long duration storm is always the design event for off-channel storage reservoirs where there is minimal area tributary to the reservoir. Intermediate duration storms in eastern Washington have rarely been found to be the controlling event for design of project hydraulic works.

1.2.3 Design Storm Areal Coverage

When conducting rainfall-runoff modeling, precipitation volume and intensity are often treated as "lumped" values. That is, the computer representation of precipitation does not explicitly depict the spatial variability over the watershed. Rather, the precipitation amounts in the hyetograph are taken to represent precipitation averaged over the tributary watershed. Accordingly, the terms *Small Watershed* and *Large Watershed* are used herein to describe the relative relationship between the size of the watershed of interest and size of the design storm. For small watersheds, point precipitation closely approximates values averaged over the watershed. Conversely for large watersheds, areal distribution of the storm and attenuation from the storm center(s) can result in average precipitation values being significantly smaller than maximum point rainfall. In this case, adjustments must be made to the maximum point rainfall depth (at-site depth) so that the design storm hyetograph reflects the basin average value.

Specifically, areal adjustments are needed when the watershed under investigation exceeds 10 mi^2 and a long duration or intermediate duration storm is the design event. Areal adjustments are also needed when the watershed under investigation is larger than 1 mi^2 and a short duration thunderstorm is the design event. Additional information on storm attenuation and areal adjustments can be found in *Characteristics of Extreme Precipitation Events in Washington State*[3], HMR-57[4] and NOAA Atlas 2[6]. An abbreviated listing of that information is shown in Table 1.

TABLE 1. AREAL ADJUSTMENTS TO ACCOUNT FOR STORM SPATIAL DISTRIBUTION AS PERCENTAGE OF AT-SITE PRECIPITATION AMOUNT

WATERSHED SIZE	STORM INTERDURATIONS					
	¼ HR	1 HR	3 HR	6 HR	24 HR	72 HR
SHORT DURATION STORM 1 Mi^2	100%	100%	100%	100%	-	-
2 Mi^2	93%	97%	98%	99%	-	-
5 Mi^2	80%	88%	91%	92%	-	-
10 Mi^2	69%	79%	83%	85%	-	-
INTERMEDIATE & LONG DURATION STORMS 10 Mi^2	100%	100%	100%	100%	100%	100%
20 Mi^2	94%	94%	95%	96%	98%	98%
50 Mi^2	84%	84%	88%	91%	95%	95%
100 Mi^2	75%	75%	83%	85%	92%	92%

1.3 LAYOUT OF TECHNICAL NOTE

The following sections of this technical note are arranged in the same order as that used for construction of design storms. Example computational procedures for constructing design storms are also contained in Appendix D. Application of the design storms in rainfall-runoff models is discussed in Chapter 2.4 of *Part IV* of the *Dam Safety Guidelines*, titled *Inflow Design Flood.*

1.3.1 Design Storms for Small Watersheds

The majority of impoundment projects constructed in Washington are ones where the size of the watershed tributary to the project is very small relative to the areal coverage of the design storm. For these situations, no adjustments to at-site precipitation estimates are needed to account for the areal distribution of the storm over the tributary watershed. For the particular case of small watersheds, where no adjustments are required to account for storm areal distribution, standard dimensionless "default" hyetographs have been developed and are listed in Appendix C.

The standard progression for construction of candidate design storms when no areal adjustments are required is shown in Figure 1. An example of design storm construction for a small watershed is contained in Appendix D.

DETERMINE DESIGN STEP AND PROJECT DESIGN/PERFORMANCE GOAL
FROM TECHNICAL NOTE 2

COMPUTE PRECIPITATION MAGNITUDE FOR VARIOUS DURATIONS
FOR SELECTED DESIGN STEP

DEVELOP HYETOGRAPHS FOR CANDIDATE DESIGN STORMS
USING PROCEDURES FROM *Characteristics of Extreme Precipitation Events in Washington State*[3]
OR
SELECT HYETOGRAPHS FOR CANDIDATE DESIGN STORMS FROM *Appendix C*

FIGURE 1. FLOWCHART FOR CONSTRUCTION OF CANDIDATE DESIGN STORMS FOR SMALL WATERSHEDS

1.3.2 Design Storms for Large Watersheds

As discussed previously, a large watershed is one where the basin average precipitation volume varies sufficiently from the maximum point precipitation depth, that the areal distribution of the storm must be accounted for explicitly. This corresponds to watersheds which exceed 10 mi^2 when a long duration or intermediate duration storm is the design event, and watersheds larger than 1 mi^2 when a short duration thunderstorm is the design event.

Construction of a design storm hyetograph for a large watershed represents a watershed-specific application. Thus, generic hyetographs, similar to those contained in Appendix C, cannot be developed in advance of the application. The areal adjustment values in Table 1 may be used as guidance in determining if the "default" hyetographs for small watersheds contained in Appendix C may be acceptable. Alternatively, if areal adjustments will be an important element of the analysis, then watershed-specific hyetographs must be developed.

The standard progression for construction of candidate design storms when areal adjustments are required is shown in Figure 2. An example of design storm construction for a large watershed using adjustments for the spatial distribution of the storm is contained in Appendix D.

DETERMINE DESIGN STEP AND PROJECT DESIGN/PERFORMANCE GOAL
FROM TECHNICAL NOTE 2

COMPUTE PRECIPITATION MAGNITUDE FOR VARIOUS DURATIONS
FOR SELECTED DESIGN STEP

SELECT DEPTH-DURATION CURVES FOR CANDIDATE DESIGN STORMS
See Pages 42-53 of *Characteristics of Extreme Precipitation Events in Washington State*[3]

ADJUST DEPTH-DURATION CURVES TO ACCOUNT FOR STORM AREAL DISTRIBUTION
See Pages 69-70 of *Characteristics of Extreme Precipitation Events in Washington State*[3]

CONSTRUCT HYETOGRAPHS FROM ADJUSTED DEPTH-DURATION CURVES
USING PROCEDURES FROM *Characteristics of Extreme Precipitation Events in Washington State*[3]

FIGURE 2. FLOWCHART FOR CONSTRUCTION OF CANDIDATE DESIGN STORMS FOR LARGE WATERSHEDS

A detailed discussion of the adjustment of the depth-duration curve and final assembly of the hyetograph is described in *Characteristics of Extreme Precipitation Events in Washington State*[3]. Rather than duplicate those procedures herein, the reader will be referred to the original document.

2. SELECTION OF THE DESIGN STEP

Procedures for selection of the Design Step are discussed in detail in Technical Note 2, *Selection of Design/Performance Goals for Critical Project Elements*[1]. The relationship between the design steps and the design/performance goals is also explained in Technical Note 2. The Design Step format as applied to design storms is reproduced here for convenience (Figure 3).

1/500 AEP 1	2	3	4	5	6	7	8 PROBABLE MAXIMUM PRECIPITATION
D E S I G N S T E P							

10^{-3} 10^{-4} 10^{-5} 10^{-6}

DESIGN/PERFORMANCE GOAL - ANNUAL EXCEEDANCE PROBABILITY

FIGURE 3. DESIGN STEP FORMAT AS APPLIED TO DESIGN STORMS

2.1 RELATIONSHIP OF DESIGN STEP TO PROBABLE MAXIMUM PRECIPITATION

When Design Step 8 is indicated as the appropriate design level, Probable Maximum Precipitation[4] (PMP) is taken to be the design storm magnitude. However, this does not necessarily infer that PMP will provide a level of protection commensurate with a design/performance goal of 10^{-6} AEP.

It should be remembered that PMP is a deterministic procedure which does not employ probabilistic methods. As such, an Annual Exceedance Probability (AEP) has not been assigned to PMP by the National Oceanic and Atmospheric Administration (NOAA). Conversely, based on regional analyses of precipitation maxima (Schaefer[2]), it appears that the AEP of PMP varies widely across Washington. It can be shown to vary with both geographic location and duration, from a minimum of about 10^{-4} AEP to perhaps 10^{-8} AEP. It is unclear at this writing how Hydrometeorological Report (HMR) 57[4] (the revision to HMR-43[5]) will alter PMP estimates and thus affect the actual level of protection afforded by a PMP design.

2.1.1 Constraints on PMP Applications

It must be recognized that PMP values are estimates. Those estimates, like probabilistic estimates, are subject to uncertainties. Recognizing these uncertainties and the very large variability across the state in the actual level of protection likely afforded by PMP, it was determined that a minimum design/performance goal must also be met for PMP applications. This requirement provides improved consistency of application and avoids the potential for underdesign. Therefore, when Design Step 8 is indicated and PMP is selected, the actual precipitation value used in design must be at least as large as that associated with an event with a computed AEP of 10^{-5}. It is anticipated that this constraint will have applicability primarily in the coastal areas.

3. COMPUTATION OF PRECIPITATION MAGNITUDE

Studies over the past decade have demonstrated that regionalization techniques (Hosking[8,12], Potter[13], Wallis[14], National Research Council[9]) for estimation of magnitude-frequency characteristics are often vastly superior to past practices of single station analyses. The procedures used herein to estimate precipitation magnitude-frequency characteristics are based on procedures contained in *Regional Analyses of Precipitation Annual Maxima in Washington*[3] and information contained in the National Weather Service document NOAA Atlas 2[6]. These procedures have been supplemented by additional research and contain small refinements to the original work. In particular, the four parameter KAPPA Distribution (Hosking[11,12]) has replaced the three parameter Generalized Extreme Value (GEV) distribution for describing the annual maxima data.

3.1 FRAMEWORK FOR COMPUTING MAGNITUDE-FREQUENCY CHARACTERISTICS

For most investigations, it is necessary to develop several candidate design storms to allow an analysis of the response of the reservoir and spillway(s) to various flood characteristics. The principal storm characteristics which affect the flood peak discharge, runoff volume and hydrograph shape are the precipitation intensity, volume and duration. The range of these storm characteristics can be suitably described using three candidate storms, one for each of three durations. The terms Short Duration, Intermediate Duration and Long Duration are used herein as labels to differentiate between the durations of the candidate design storms.

It will be seen later that the precipitation amounts for the 2 hour, 6 hour and 24 hour durations are to be used as index amounts to scale the depth-duration curves and hyetographs for the short, intermediate and long duration candidate design storms respectively.

The first step in developing the candidate storms is to compute the precipitation magnitude for each storm duration for the geographic location of interest. To simplify computational procedures, the estimation of the precipitation magnitude (quantile estimate) for any Annual Exceedance Probability (AEP) of interest can be expressed in the following form (Chow[7]):

$$X_i = \overline{X} \left(1 + K_i C_v \right) \tag{1}$$

where:

- X_i = Precipitation estimate for the selected AEP
- $\overline{X}$ = At-site mean for the duration of interest
- K_i = Frequency factor for the KAPPA distribution for the regional value of L-Skewness (τ_3) and the selected AEP
- C_v = Regional value of the coefficient of variation

In most applications, representative precipitation measurements from nearby gages are rarely available. Thus, precipitation statistics for a specific geographic location (at-site statistics) must be obtained through regionalization techniques which utilize data from the existing gaging network. The procedures in Sections 3.1.1 and 3.1.2 are intended for use in those situations where no nearby gaging data are available. Information in Section 3.1.3 can be used to augment these procedures when gaging data is available.

The procedures for estimation of precipitation magnitude-frequency characteristics are listed below and are discussed in detail in the following sections.

Procedures for Estimation of Precipitation Magnitude-Frequency Characteristics

1. Determine the Mean Value (At-Site Mean) of the Annual Maxima Series for the Geographic Location and Duration of Interest.

2. Determine the Regional Parameters of the Coefficient of Variation (C_v) and L-Skewness (τ_3) for the Duration of Interest.

3. Determine the Frequency Factor (K_{ds}) for the Selected Design Step.

4. Compute the Estimate of the Precipitation Depth for the Duration of Interest using the At-Site Mean and Regional Parameters for the Geographic Location of Interest.

3.1.1 Determination of At-Site Mean

As listed above, the determination of the at-site mean is the first step in computation of the design storm depth and magnitude-frequency characteristics. Determination of the at-site mean for the 2 hour duration can be computed using equation 2 and procedures discussed in Section 3.1.1.1.

The at-site mean for the 6 hour and 24 hour durations can be computed directly based on the 2 year partial duration series values contained in the National Weather Service (NWS) publication NOAA Atlas 2[6] in conjunction with equation 2. Selected precipitation-frequency maps from NOAA Atlas 2 are reproduced in Appendix A. For all durations, the at-site mean can be computed as:

$$\overline{X} = \frac{.88X_{2p}}{[1 + K_2C_v]} \qquad (2)$$

where:

$\overline{X}$ = Precipitation at-site mean for the geographic location and duration of interest

X_{2p} = 2 year partial duration series precipitation amount from NOAA Atlas 2 for the geographic location and duration of interest

K_2 = Frequency factor for the 2 year event (Appendix B, Tables B1 and B2)

C_v = Regional value of the coefficient of variation for the geographic location and duration of interest (Figures 5a, 5b)

3.1.1.1 2 Hour At-Site Mean

Computation of the at-site mean for the 2 hour duration is based on the regression equations contained in NOAA Atlas 2[6]. Specifically, the regression equations listed below are used to compute the 2 year partial duration value (X_2). The computed value of X_2 corresponds to X_{2p} and is then utilized in equation 2 to compute the 2 hour at-site mean. An isohyetal map of the 2 hour - 2 year partial duration series values (X_2) is also shown in Appendix A for informational purposes.

The regression equations for the various climatic regions in Washington (Figure 4) are listed below:

Puget Sound Lowlands and Coastal Areas - Regions 3 & 5

$$X_2 = .119 + .240X_6 + .390\frac{X_6^2}{X_{24}} \tag{3}$$

Mountainous Areas of Western Washington - Region 4

$$X_2 = .122 + .240X_6 + .395\frac{X_6^2}{X_{24}} \tag{4}$$

Mountainous Areas of Eastern Washington - Region 1

$$X_2 = .014 + .250X_6 + .533\frac{X_6^2}{X_{24}} + .0008Z \tag{5}$$

Columbia Basin and Non-Orographic Areas of Eastern Washington - Region 2

$$X_2 = .056 + .278X_6 + .245X_{24} - .0003L_1L_2 \tag{6}$$

where:

X_2 = 2 hour, 2 year partial duration series value
X_6 = 6 hour, 2 year partial duration series value from NOAA Atlas 2
X_{24} = 24 hour, 2 year partial duration series value from NOAA Atlas 2
Z = Elevation in hundreds of feet
L_1 = Latitude (degrees) - 40°
L_2 = Longitude (degrees) - 100°

3.1.2 Determination of Regional Parameters

The fundamental precept of a regional analysis is that a climatologically homogeneous region can be delineated. A homogeneous region is one wherein the precipitation annual maxima, after division (scaling) by the at-site mean, can be described by a common probability distribution having common measures of dispersion and skewness. In Washington, it was found by Schaefer[3] that the State could be considered to be a super-region where the regional measure of dispersion (the regional coefficient of variation C_v) and the regional measure of skewness (L-Skewness τ_3) were found to vary systematically with Mean Annual Precipitation (MAP) and duration (Figures 5a,5b,6a,6b).

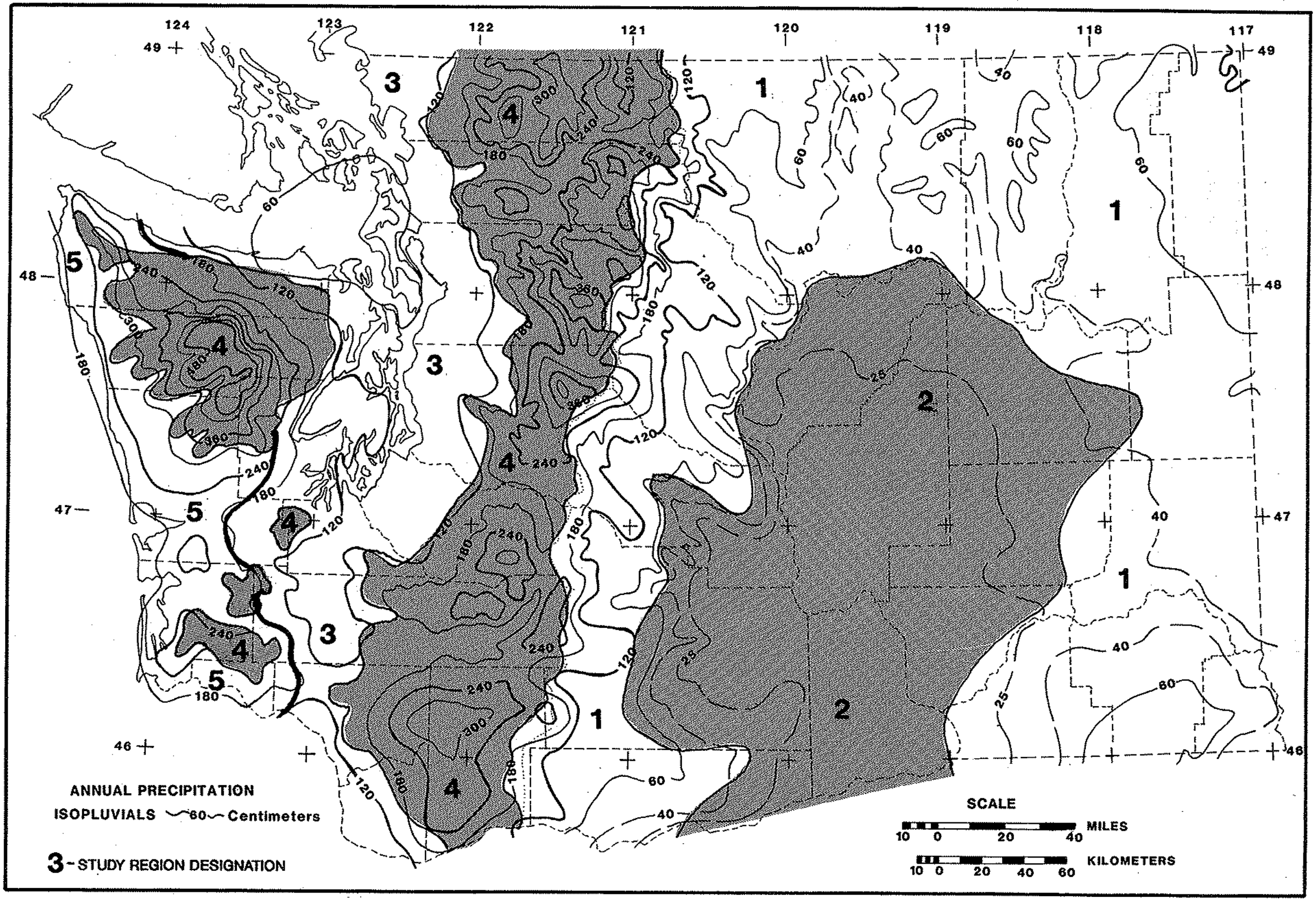
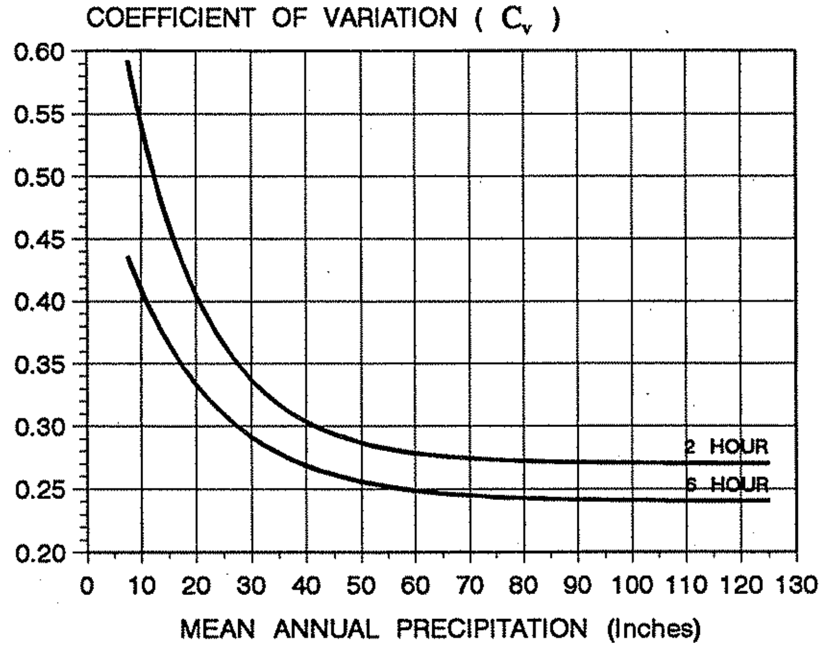
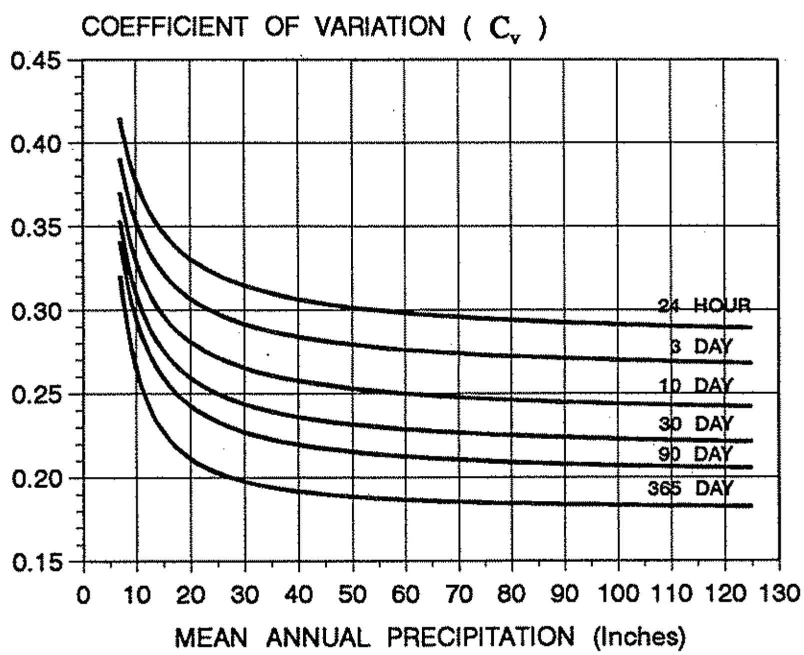


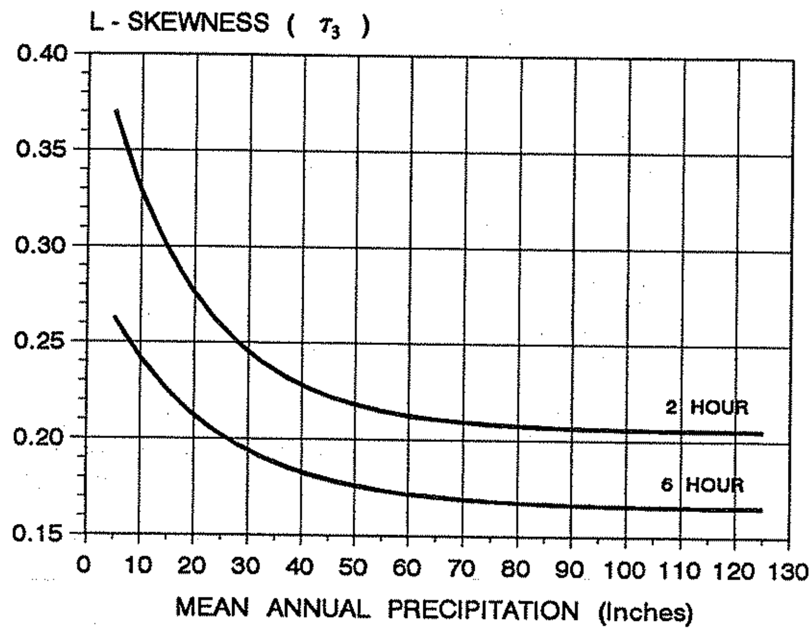
FIGURE 4. CLIMATIC REGIONS IN WASHINGTON

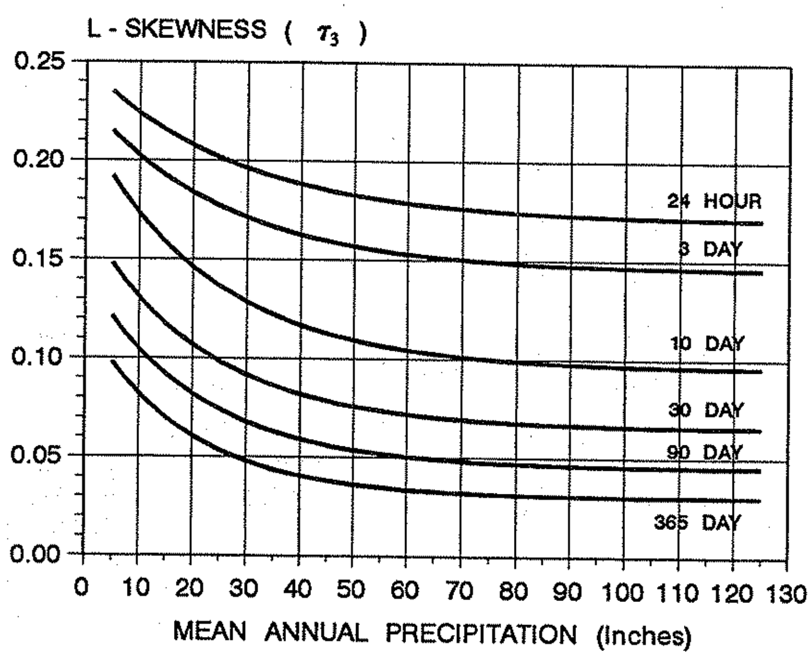
The regional parameters C_v and τ_3 are displayed in Figures 5a,5b and 6a,6b respectively, and values from the graphs may be used directly in computational procedures once a value of the MAP (Appendix A) for the geographic location of interest has been obtained.





FIGURES 5a, 5b RELATIONSHIP OF REGIONAL COEFFICIENT OF VARIATION WITH MEAN ANNUAL PRECIPITATION AND DURATION





FIGURES 6a, 6b RELATIONSHIP OF REGIONAL L-SKEWNESS WITH MEAN ANNUAL PRECIPITATION AND DURATION

3.1.3 Adjustment of At-Site Parameters Based on Data from a Nearby Gaging Station

Adjustment of the at-site mean, and regional C_v determined in the previous section can be made when annual maxima data are available from a nearby precipitation gage. However, it must be remembered that transposition of this data to the geographic location under consideration is only valid if the gage site is deemed climatically representative of the site under consideration. Inferences on the validity of this situation can often be obtained by a review of the behavior of the Mean Annual Precipitation (MAP) and typical precipitation maxima in the vicinity. Some of this information is available on the precipitation maps contained in Appendix A.

If it is determined that the data from the nearby station is representative of the site under consideration, then an improved estimate of the at-site mean and coefficient of variation can be made. This is accomplished using a type of linear empirical Bayes estimator recommended by Kuczera[15]. It is based on a weighted average of the regional and station statistics. Separate computations are needed for each of the 2 hour, 6 hour and 24 hour durations.

3.1.3.1 Adjustment to At-Site Mean

$$\overline{X}_* = \overline{X} + \left[\frac{A}{A + B}\right]\left[\overline{X}_s - \overline{X}\right] \tag{7}$$

where:

$\overline{X}_*$ = Improved estimate of at-site mean
$\overline{X}$ = Original value of at-site mean from procedures in Section 3.1.1
$\overline{X}_s$ = Value of at-site mean computed from station data

A = Measure of variance of regional data, $A = .045^2$
B = Measure of variance of station data

$$B = \frac{C_{vs}^{\ 2}}{N_s} \tag{8}$$

C_{vs} = Coefficient of variation of station data
N_s = Number of years of record at station

3.1.3.2 Adjustment to Regional Coefficient of Variation

Adjustment of the regional coefficient of variation proceeds in a manner similar to that for the at-site mean. The improved estimate of the regional coefficient of variation is computed as follows.

$$C_{v*} = C_v + \left[\frac{D}{D + E}\right]\left[C_{vs} - C_v\right] \tag{9}$$

where: C_{v*} = Improved estimate of regional coefficient of variation
C_v = Coefficient of Variation for region from Section 3.1.2

D = Measure of variance of regional data, 2 Hr data $D = .0080^2$
6 Hr data $D = .0097^2$
24 Hr data $D = .0127^2$

E = Measure of variance of station data

$$E = \frac{C_{vs}^{\ 2}}{2N_s} \tag{10}$$

C_{vs} = Coefficient of variation of station data
N_s = Number of years of record at station

The (*) values of the mean and coefficient of variation in equations 7 and 9 represent weighted averages and the best estimates. They are to be used with equation 1 for computation of precipitation magnitudes.

3.1.4 Determination of Frequency Factor for Design Step

For any given probability distribution, it is possible to develop a table of frequency factors which can be used with equation 1 to establish the relationship between the precipitation annual maxima and the exceedance probability. Tables of frequency factors for the KAPPA distribution for various exceedance probabilities and the full range of design steps are contained in Appendix B.

3.1.5 Computation of Precipitation Magnitude for Design Storms

Computation of the precipitation magnitude for the 2 hour, 6 hour and 24 hour durations follows directly from the use of equation 1 with the parameters for the at-site mean and regional values of the coefficient of variation and L-Skewness. Equation 1 is rewritten here for convenience.

$$X_{ds} = \overline{X}\ (\ 1\ +\ K_{ds}C_v\ ) \tag{11}$$

where: X_{ds} = Precipitation estimate for the design step and selected AEP
$\overline{X}$ = At-site mean for the duration of interest,
$(\overline{X})$ is replaced by $(\overline{X}_*)$ when nearby gage data is used to adjust $(\overline{X})$
K_{ds} = Frequency factor for the KAPPA distribution for the regional value of L-Skewness (τ_3) and the selected design step
C_v = Regional value of the coefficient of variation
(C_v) is replaced by (C_{v*}) when nearby gage data is used to adjust (C_v)

3.1.5.1 Determination of Design Precipitation Magnitude for Large Watersheds

Computation of the design precipitation magnitude for large watersheds is often complicated by the fact that the precipitation magnitude for a selected AEP may vary considerably across the watershed. In this case, a representative value for the selected AEP or design step is obtained by computing a basin average value. This is accomplished by placing a grid network over the watershed and computing both at-site means and regional values of C_v and τ_3 for the nodes on the grid. These values are then used to compute quantile estimates at the nodes. The quantile estimates can then be used to obtain a weighted average (basin average) which is representative of the watershed.

3.1.5.2 Design Usage

Use of equations 1 and 11 with the at-site and regional parameters yields quantile estimates (magnitude-frequency estimates) which are expected values. In engineering design applications, it is common practice to incorporate some design conservatisms to account for uncertainties and to provide protection from underdesign. For probabilistic methods, accounting for uncertainties usually employs some type of confidence interval. Monte Carlo analyses have been conducted to investigate the uncertainties of quantile estimates considering the variability in estimation of the at-site mean and the regional parameters C_v and τ_3. Based on these findings, it was determined that an overage of 15% would provide about an 80% level of protection from underdesign. Thus, all precipitation values computed by equations 1 and 11 which are to be used in a design application are to be increased by 15% as shown in equation 12.

$$P_d = 1.15X_{ds} \tag{12}$$

where:

P_d = Precipitation amount to be used in design application

X_{ds} = Precipitation estimate for the design step and selected AEP (equation 11)

3.1.6 Development of Precipitation Magnitude-Frequency Curve

A precipitation magnitude-frequency curve can be generated by repeated use of equation 1 for a range of exceedance probabilities listed in the Tables in Appendix B. Extreme Value Type I plotting paper is also contained in Appendix B which may be copied and used for plotting the frequency curve. Again it is emphasized that these estimates are expected values. It is standard practice to increase these values when used for design of critical project elements.

4. DEVELOPMENT OF HYETOGRAPHS

The time history of precipitation depth/intensity at a given location or over a specific area is described by a hyetograph. The hyetograph is the standard form by which precipitation is input to rainfall-runoff computer models. It is common knowledge that the temporal and spatial distribution of precipitation, as described by a hyetograph, are stochastic and vary widely from storm to storm. Therefore, it is important that hyetographs used in design/evaluation be developed using probabilistic procedures which allow the user to incorporate features which reflect the manner in which extreme storms have historically occurred (Schaefer[3]).

The procedures utilized here for construction of hyetographs are based on probabilistic analyses of extreme storms in Washington. A thorough discussion of those procedures is not presented here, but is contained in *Characteristics of Extreme Precipitation Events in Washington State*[3]. Information and procedures from that document have been used to develop hyetographs for small watersheds.

It is intended that the simplified methods presented in Section 4.2.2 will allow the user easy access to the library of dimensionless hyetographs contained in Appendix C and listed on the enclosed diskette.

4.1 CANDIDATE DESIGN STORMS

As discussed previously, it is usually necessary to develop several candidate design storms to allow an analysis of the response of the reservoir and spillway(s) to various flood characteristics. The principal storm characteristics which affect the flood peak discharge, runoff volume and hydrograph shape are the precipitation intensity, volume and duration. The range of these storm characteristics can be suitably described using several candidate storms, reflecting a range of storm durations. The following hyetographs (Figures 7, 8, and 9a, 9b) are presented to display the basic characteristics of short, intermediate and long duration design storms. They were developed by scaling the dimensionless hyetographs contained in Appendix C by selected 2 hour, 6 hour and 24 hour precipitation amounts, respectively.

4.1.1 Example Short Duration Design Hyetograph

Short duration design hyetographs have a duration of 6 hours and are used to model the convective nature of local storms. These hyetographs are characterized by very high precipitation intensities occurring over limited geographical areas during the warm season.

The ordinates of the short duration dimensionless design hyetograph for the Central basin in eastern Washington (Appendix C) was scaled by a 2 hour precipitation amount of 2 inches to produce an example of a short duration mass and intensity hyetograph (Figure 7).

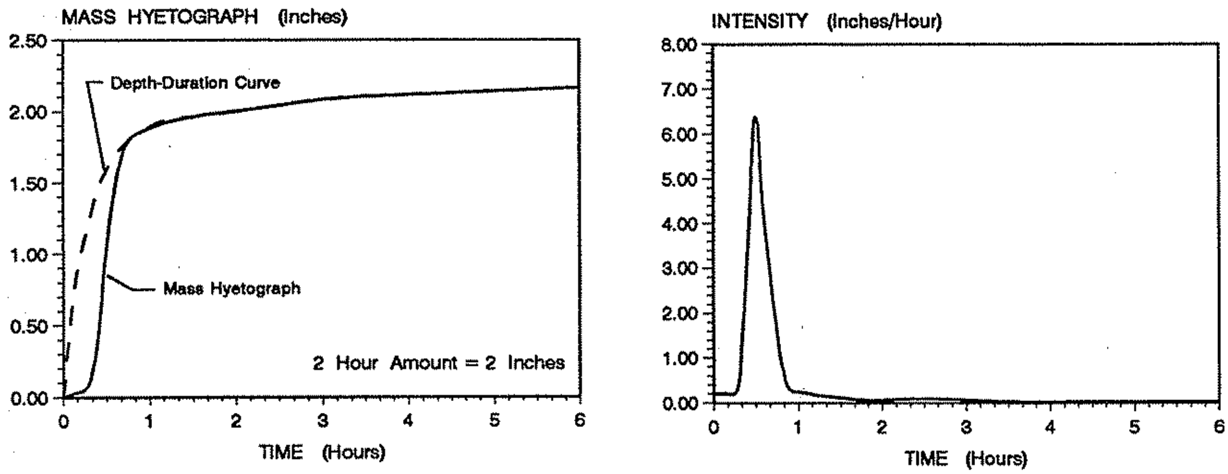


FIGURE 7. EXAMPLE SHORT DURATION HYETOGRAPH

4.1.2 Example Intermediate Duration Design Hyetographs

Intermediate duration design hyetographs have a duration of 18 hours and are used to model general storm activity. These hyetographs are characterized by high precipitation intensities and relatively large precipitation volume which predominately occur in the fall and winter season on both sides of the Cascades and in the spring in Eastern Washington.

The ordinates of the intermediate duration dimensionless design hyetograph for the mountainous areas of western Washington (Appendix C) was scaled by a 6 hour precipitation amount of 3 inches to produce an example of an intermediate duration mass and intensity hyetograph (Figure 8).

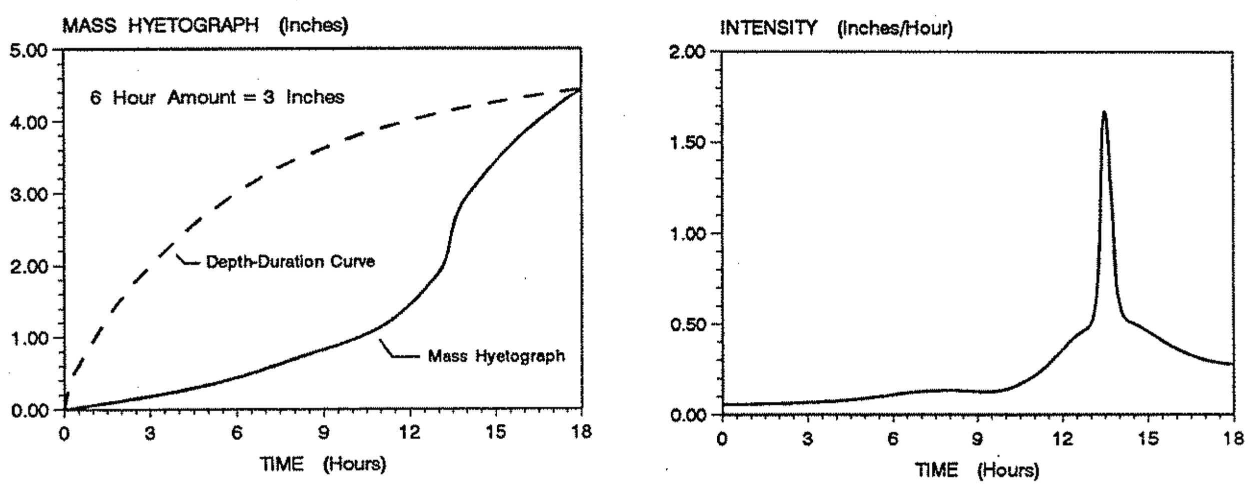


FIGURE 8. EXAMPLE INTERMEDIATE DURATION HYETOGRAPH

4.1.3 Example Long Duration Design Hyetographs

Long duration design hyetographs have a duration of 72 hours and are used to model general storm activity in the late fall and winter months. These hyetographs are characterized by a large total volume and contain relatively moderate and uniform precipitation intensities.

There are two types of long duration hyetographs to be considered. One incorporates higher intensities but a smaller total volume (Figure 9a). The second type contains very moderate and uniform intensities but has a greater total depth (Figure 9b). The ordinates of the long duration dimensionless design hyetographs for the Puget Sound Lowlands of western Washington (Appendix C) were scaled by a 24 hour precipitation amount of 6 inches to produce examples of long duration mass and intensity hyetographs (Figures 9a,9b).

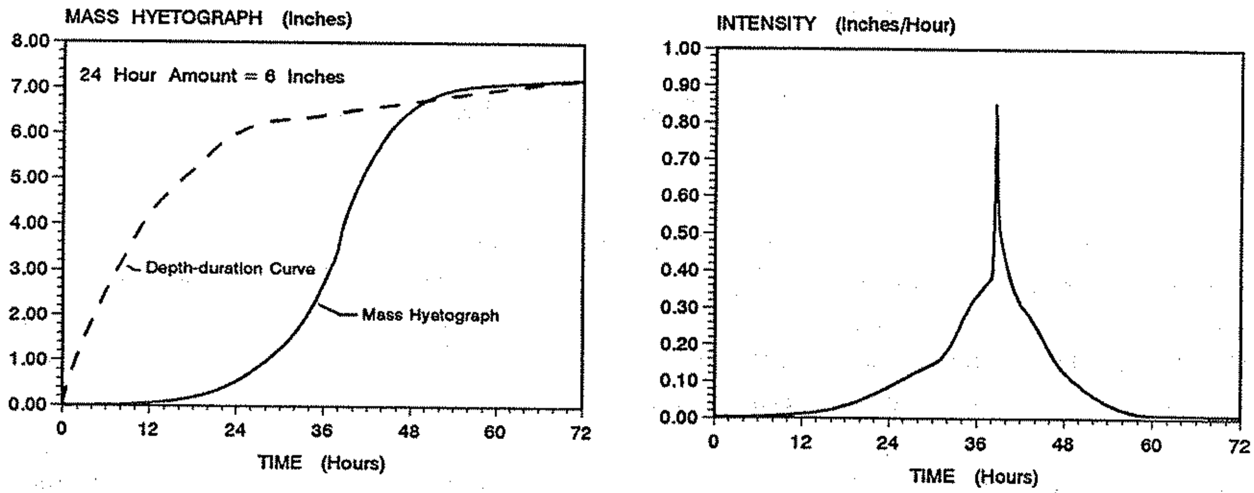


FIGURE 9a EXAMPLE LONG DURATION HYETOGRAPH - EMPHASIS ON INTENSITY

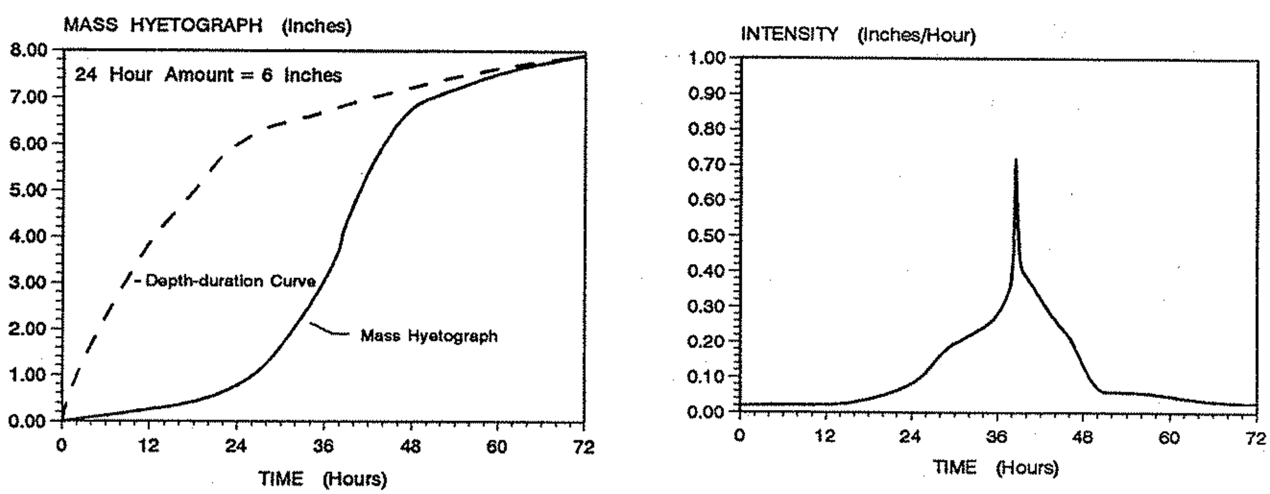


FIGURE 9b EXAMPLE LONG DURATION HYETOGRAPH - EMPHASIS ON VOLUME

4.2 HYETOGRAPHS FOR SMALL WATERSHEDS

Probabilistic information and procedures from Schaefer[3] have been used to develop two types of hyetographs, typical and design hyetographs, for application on small watersheds. These hyetographs are applicable to the five climatic regions in the state (Figure 4) for short, intermediate and long duration storms. These hyetographs may be used directly, or alternatively, the user may elect to develop other hyetographs using procedures from *Characteristics of Extreme Precipitation Events in Washington State*[3] or procedures from HMR-57[4] to meet site-specific project needs.

4.2.1 Typical and Design Hyetographs

A typical hyetograph is one which contains characteristics which have been commonly observed to occur in an extreme storm in a given region at the selected duration. Typical hyetographs contain mean values or 50% exceedance values for such storm features as: the exceedance probability of the depth-duration curve; the resultant magnitude of intensities and total depth; the time of occurrence of the peak intensity; and the sequencing of incremental precipitation amounts.

A typical hyetograph is normally used in rainfall-runoff modeling when one is interested in investigating the typical flood response from a watershed. For example, this type of hyetograph can be used for generating a flood frequency curve on an ungaged watershed. It can also be used to assist in calibrating runoff and basin response parameters on a gaged watershed or where flood frequency information is available. Dimensionless typical hyetographs are listed in electronic form in files on the diskette which accompanies this technical note.

A design hyetograph incorporates more conservative selections of storm elements. As the name implies, this type of hyetograph is intended for design applications where greater conservatism is warranted. All probabilistic features of intermediate and long duration design hyetographs utilized here correspond to exceedance probabilities of 20% (one chance in five that a more rare event/sequence/etc. could occur). Probabilistic features of short duration hyetographs correspond to exceedance probabilities of 33% (one chance in three that a more rare event/sequence/etc. could occur).

4.2.2 Design Hyetograph Construction

Appendix C contains a library of hyetographs for use on small watersheds. The design hyetographs are also listed in electronic form in files on the diskette which accompanies this technical note.

Design hyetographs can be constructed by scaling these dimensionless hyetographs by the design precipitation amount (P_d) for the selected duration. As discussed previously, the precipitation amounts for the 2 hour, 6 hour and 24 hour durations are used to scale the dimensionless hyetographs to construct the short, intermediate, and long duration design hyetographs, respectively. Example D1 in Appendix D describes the complete process of constructing a design hyetograph for a small watershed.

4.3 HYETOGRAPHS FOR LARGE WATERSHEDS

The hyetographs contained in Appendix C cannot be modified for use on larger watersheds. Adjustments for areal distribution must first be made to the selected depth-duration curve. The hyetograph can then be assembled from the incremental precipitation amounts in the depth-duration curve. These procedures are discussed in detail in *Characteristics of Extreme Precipitation Events in Washington State*[3] in the section titled *Methodology for Assembly of Synthetic Storms*. The reader is referred to that document (particularly example 3, page 82) for procedures to construct hyetographs for large watersheds. Example D2 in Appendix D also describes the process of constructing a design hyetograph for a large watershed.

4.3.1 Guidance in Selecting Parameters for Construction of Typical and Design Hyetographs

The following guidance is given for use with the document above for construction of typical and design hyetographs on large watersheds.

TABLE 2. RECOMMENDED PARAMETERS FOR DEVELOPING TYPICAL HYETOGRAPHS

HYETOGRAPH PARAMETER	SHORT DURATION	INTERMEDIATE DURATION	LONG DURATION
Exceedance Probability of Selected Depth-Duration Curve	50%	50%	50%
Exceedance Probability of Time of Occurrence of High Intensity Precipitation	50% or Mean Value	50% or Mean Value	50% or Mean Value
Exceedance Probability of Other Storm Elements	50% or Mean Value	50% or Mean Value	50% or Mean Value

TABLE 3. RECOMMENDED PARAMETERS FOR DEVELOPING DESIGN HYETOGRAPHS

HYETOGRAPH PARAMETER	SHORT DURATION	INTERMEDIATE DURATION	LONG DURATION
Exceedance Probability of Selected Depth-Duration Curve	33%	20%	20%
Exceedance Probability of Time of Occurrence of High Intensity Precipitation	33%	20%	20%
Exceedance Probability of Other Storm Elements	33%	20%	20%

5. REFERENCES

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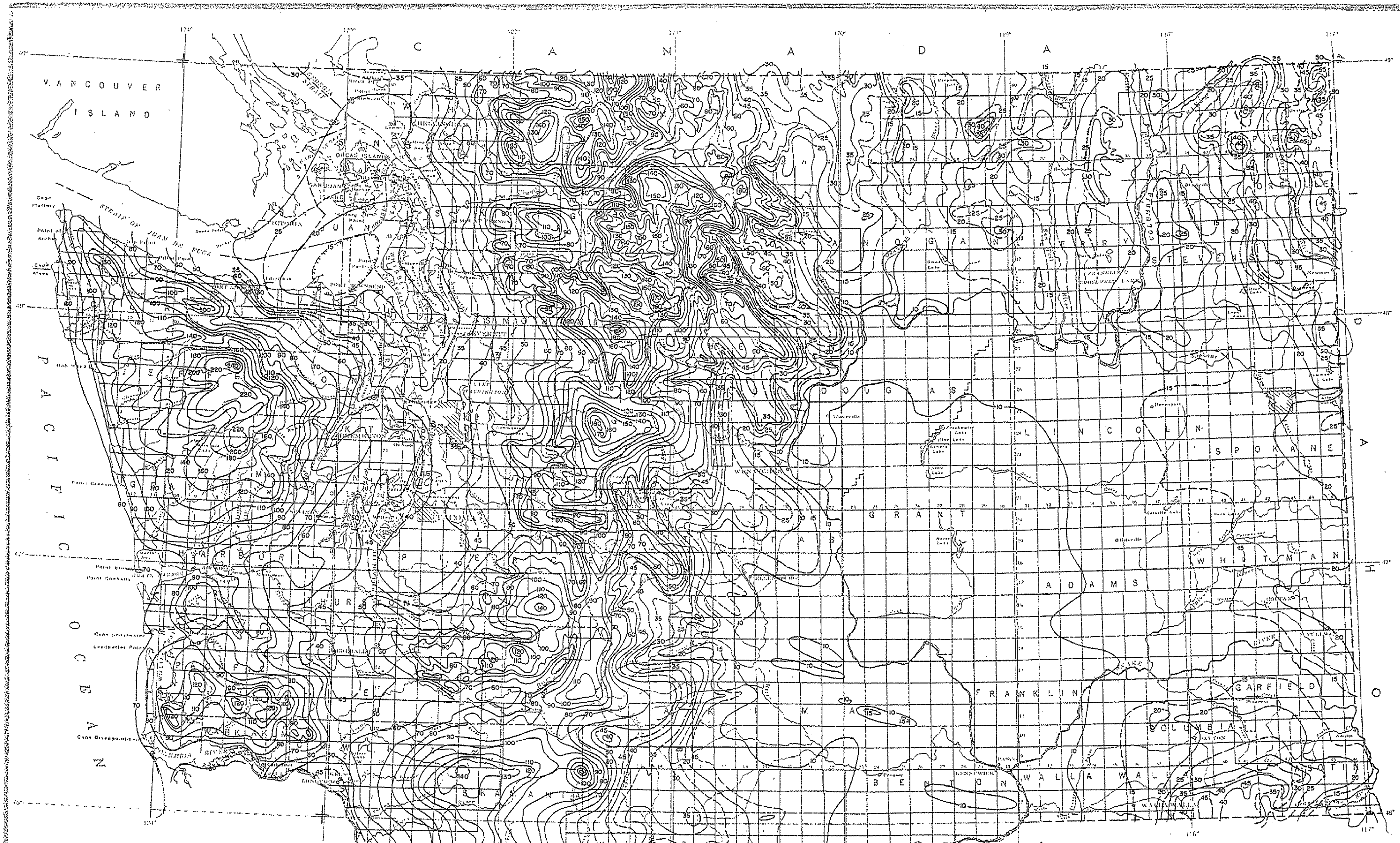
APPENDIX A

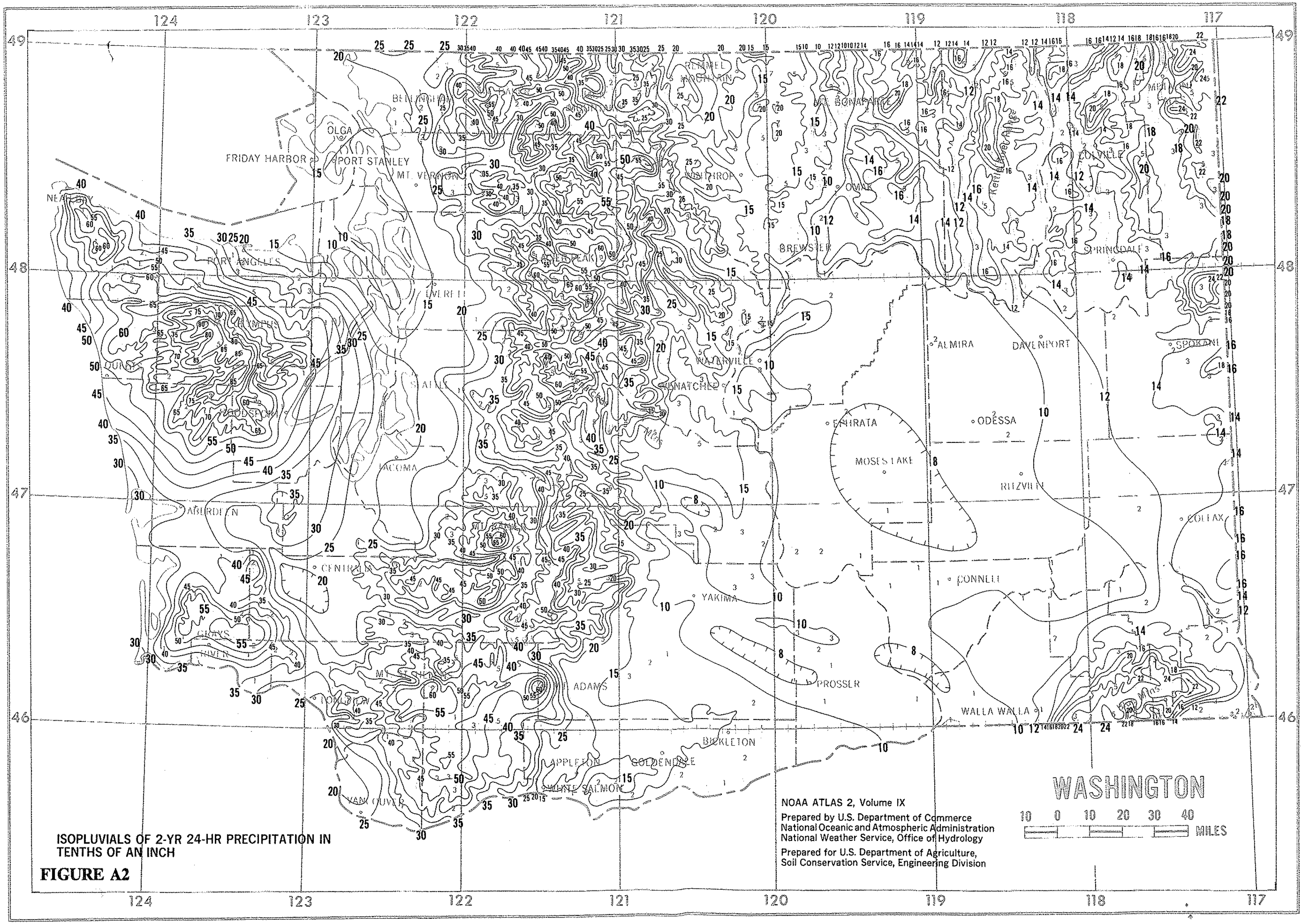
PRECIPITATION MAGNITUDE-FREQUENCY MAPS FOR WASHINGTON



Isohyetal analysis prepared by the U.S. Weather Bureau River Forecast Center, Portland, Oregon using adjusted climatological data (1930 – 57) and values derived by correlation with physiographic factors.

Published by the Soil Conservation Service, U.S. Department of Agriculture, in cooperation with the U.S Weather Bureau, U.S. Department of Commerce, March 1965.

FIGURE A1



ISOPLUVIALS OF 2-YR 24-HR PRECIPITATION IN TENTHS OF AN INCH

FIGURE A2

NOAA ATLAS 2, Volume IX

Prepared by U.S. Department of Commerce
National Oceanic and Atmospheric Administration
National Weather Service, Office of Hydrology

Prepared for U.S. Department of Agriculture,
Soil Conservation Service, Engineering Division

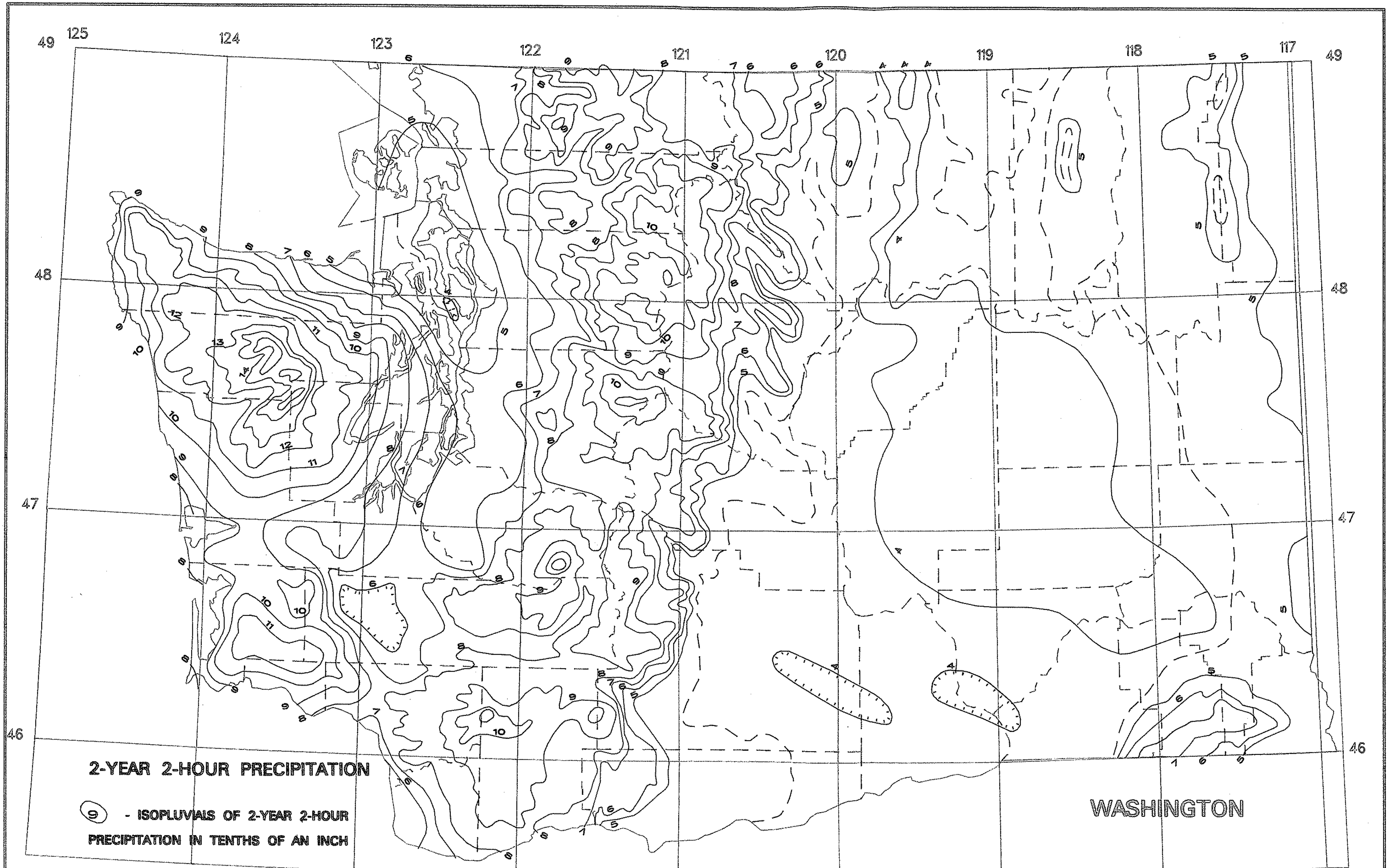
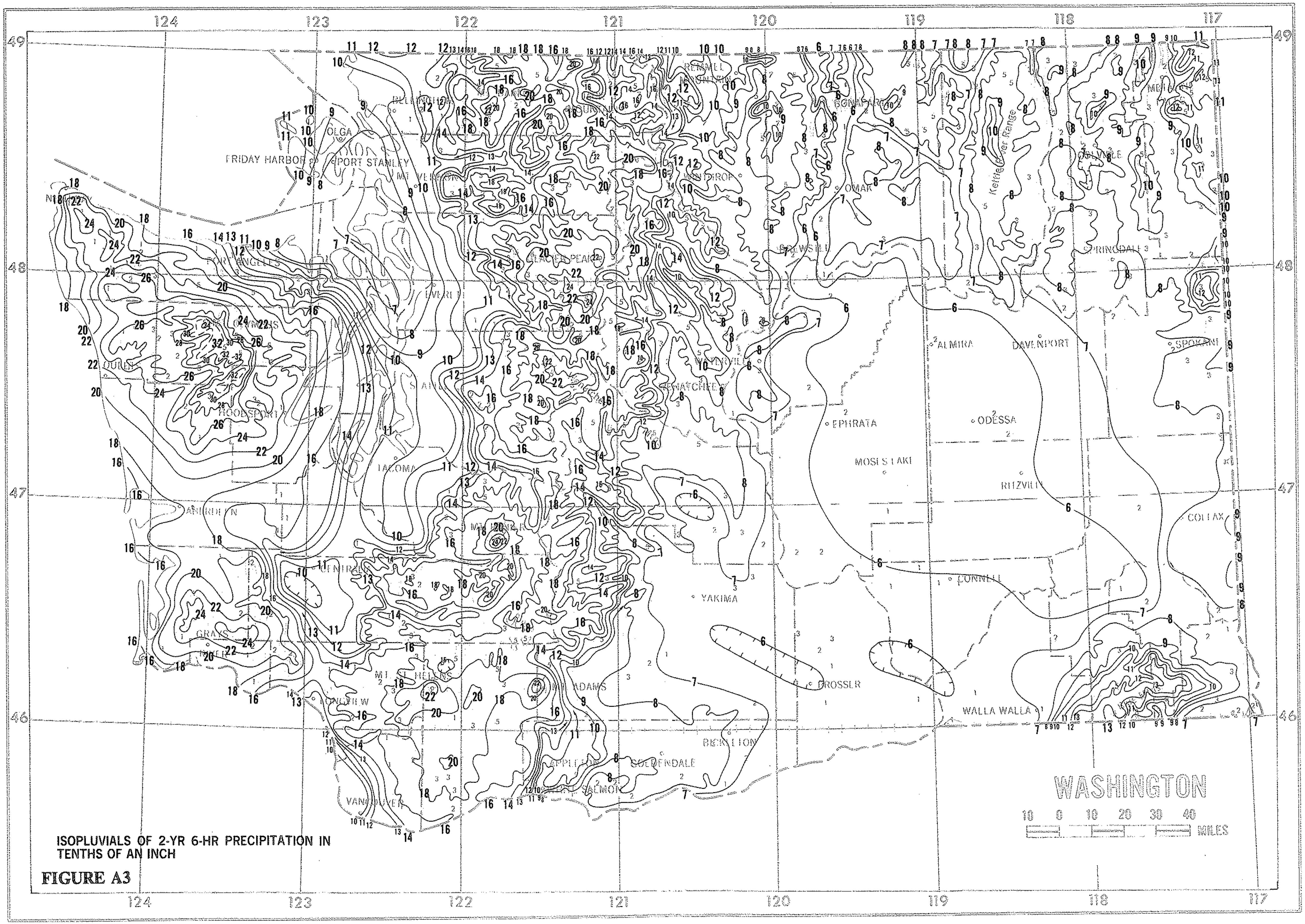

2-YEAR 2-HOUR PRECIPITATION
9 - ISOPLUVIALS OF 2-YEAR 2-HOUR PRECIPITATION IN TENTHS OF AN INCH
WASHINGTON

FIGURE A4



ISOPLUVIALS OF 2-YR 6-HR PRECIPITATION IN TENTHS OF AN INCH

FIGURE A3

APPENDIX B

FREQUENCY FACTORS FOR THE KAPPA DISTRIBUTION

TABLE B1. FREQUENCY FACTORS FOR WESTERN WASHINGTON

KAPPA DISTRIBUTION h= -0.10

τ3	2 YR	10 YR	25 YR	100 YR	STEP 1	STEP 2	STEP 3	STEP 4	STEP 5	STEP 6	STEP 7	STEP 8
.000	-.004	1.30	1.76	2.27	2.68	2.81	2.99	3.13	3.23	3.31	3.37	3.41
.005	-.009	1.30	1.77	2.30	2.72	2.86	3.05	3.20	3.31	3.39	3.46	3.51
.010	-.015	1.31	1.78	2.32	2.77	2.91	3.11	3.27	3.39	3.48	3.55	3.61
.015	-.020	1.31	1.79	2.35	2.81	2.97	3.18	3.34	3.47	3.57	3.65	3.71
.020	-.025	1.31	1.80	2.37	2.85	3.02	3.24	3.42	3.56	3.67	3.75	3.82
.025	-.030	1.31	1.81	2.40	2.90	3.07	3.31	3.50	3.65	3.76	3.86	3.94
.030	-.035	1.31	1.82	2.43	2.95	3.13	3.38	3.58	3.74	3.87	3.97	4.06
.035	-.040	1.32	1.83	2.45	2.99	3.18	3.45	3.66	3.83	3.98	4.09	4.18
.040	-.045	1.32	1.84	2.48	3.04	3.24	3.52	3.75	3.93	4.09	4.21	4.32
.045	-.050	1.32	1.85	2.51	3.09	3.30	3.59	3.83	4.04	4.20	4.34	4.45
.050	-.055	1.32	1.86	2.53	3.14	3.36	3.67	3.93	4.14	4.32	4.48	4.60
.055	-.060	1.32	1.87	2.56	3.19	3.42	3.74	4.02	4.25	4.45	4.62	4.76
.060	-.064	1.32	1.88	2.59	3.24	3.48	3.82	4.12	4.37	4.58	4.76	4.92
.065	-.069	1.32	1.89	2.61	3.29	3.54	3.91	4.22	4.49	4.72	4.92	5.09
.070	-.074	1.32	1.90	2.64	3.34	3.60	3.99	4.32	4.61	4.86	5.08	5.27
.075	-.079	1.32	1.91	2.67	3.39	3.67	4.07	4.43	4.74	5.01	5.25	5.45
.080	-.084	1.32	1.92	2.69	3.45	3.73	4.16	4.54	4.87	5.17	5.43	5.65
.085	-.088	1.32	1.93	2.72	3.50	3.80	4.25	4.65	5.01	5.33	5.61	5.86
.090	-.093	1.32	1.94	2.75	3.56	3.87	4.35	4.77	5.15	5.50	5.81	6.08
.095	-.098	1.32	1.94	2.78	3.61	3.94	4.44	4.89	5.30	5.67	6.01	6.31
.100	-.102	1.32	1.95	2.80	3.67	4.01	4.54	5.02	5.46	5.86	6.22	6.56

TABLE B1. FREQUENCY FACTORS FOR WESTERN WASHINGTON

KAPPA DISTRIBUTION h= -0.10

τ_3	2 YR	10 YR	25 YR	100 YR	STEP 1	STEP 2	STEP 3	STEP 4	STEP 5	STEP 6	STEP 7	STEP 8
.100	-.102	1.32	1.95	2.80	3.67	4.01	4.54	5.02	5.46	5.86	6.22	6.56
.105	-.107	1.32	1.96	2.83	3.73	4.08	4.64	5.15	5.62	6.05	6.45	6.82
.110	-.111	1.32	1.97	2.86	3.79	4.16	4.74	5.28	5.78	6.25	6.69	7.09
.115	-.116	1.32	1.97	2.88	3.84	4.23	4.84	5.42	5.96	6.46	6.93	7.38
.120	-.120	1.32	1.98	2.91	3.90	4.31	4.95	5.56	6.13	6.68	7.19	7.68
.125	-.125	1.31	1.99	2.94	3.96	4.39	5.06	5.70	6.32	6.91	7.47	8.00
.130	-.129	1.31	1.99	2.96	4.03	4.47	5.17	5.85	6.51	7.14	7.75	8.34
.135	-.133	1.31	2.00	2.99	4.09	4.55	5.29	6.01	6.71	7.39	8.05	8.70
.140	-.137	1.31	2.01	3.02	4.15	4.63	5.41	6.17	6.92	7.65	8.37	9.07
.145	-.142	1.30	2.01	3.04	4.21	4.71	5.53	6.33	7.13	7.92	8.70	9.47
.150	-.146	1.30	2.02	3.07	4.28	4.79	5.65	6.50	7.36	8.20	9.05	9.89
.155	-.150	1.30	2.02	3.10	4.34	4.88	5.78	6.68	7.59	8.50	9.42	10.34
.160	-.154	1.29	2.03	3.12	4.41	4.97	5.91	6.86	7.83	8.81	9.80	10.81
.165	-.158	1.29	2.03	3.15	4.47	5.05	6.04	7.04	8.07	9.13	10.20	11.31
.170	-.162	1.29	2.03	3.17	4.54	5.14	6.17	7.23	8.33	9.46	10.63	11.83
.175	-.165	1.28	2.04	3.20	4.60	5.23	6.31	7.43	8.60	9.81	11.07	12.39
.180	-.169	1.28	2.04	3.22	4.67	5.32	6.45	7.63	8.87	10.17	11.54	12.97
.185	-.173	1.27	2.04	3.25	4.74	5.42	6.60	7.84	9.16	10.56	12.03	13.59
.190	-.177	1.27	2.05	3.27	4.81	5.51	6.74	8.06	9.46	10.95	12.55	14.25
.195	-.180	1.26	2.05	3.30	4.88	5.61	6.89	8.28	9.76	11.37	13.09	14.94
.200	-.184	1.26	2.05	3.32	4.94	5.70	7.05	8.50	10.08	11.80	13.66	15.67

TABLE B1. FREQUENCY FACTORS FOR WESTERN WASHINGTON

KAPPA DISTRIBUTION h= -0.10

$\tau 3$	2 YR	10 YR	25 YR	100 YR	STEP 1	STEP 2	STEP 3	STEP 4	STEP 5	STEP 6	STEP 7	STEP 8
.200	-.184	1.26	2.05	3.32	4.94	5.70	7.05	8.50	10.08	11.80	13.66	15.67
.205	-.187	1.25	2.05	3.34	5.01	5.80	7.20	8.73	10.41	12.25	14.25	16.45
.210	-.190	1.25	2.05	3.37	5.08	5.90	7.36	8.97	10.75	12.71	14.88	17.26
.215	-.194	1.24	2.05	3.39	5.15	6.00	7.52	9.22	11.11	13.20	15.54	18.13
.220	-.197	1.23	2.05	3.41	5.22	6.10	7.69	9.47	11.47	13.71	16.22	19.04
.225	-.200	1.23	2.05	3.43	5.29	6.20	7.86	9.73	11.85	14.24	16.95	20.01
.230	-.203	1.22	2.05	3.45	5.36	6.30	8.03	9.99	12.23	14.79	17.70	21.02
.235	-.206	1.21	2.05	3.47	5.43	6.40	8.20	10.27	12.64	15.36	18.49	22.09
.240	-.209	1.20	2.05	3.49	5.50	6.51	8.38	10.54	13.05	15.96	19.33	23.23
.245	-.211	1.20	2.04	3.51	5.58	6.61	8.56	10.83	13.49	16.58	20.20	24.43
.250	-.214	1.19	2.04	3.53	5.65	6.72	8.74	11.12	13.93	17.23	21.12	25.69
.255	-.217	1.18	2.04	3.55	5.72	6.82	8.93	11.42	14.39	17.90	22.08	27.03
.260	-.219	1.17	2.03	3.56	5.79	6.93	9.11	11.73	14.86	18.60	23.08	28.43
.265	-.221	1.16	2.03	3.58	5.85	7.03	9.31	12.05	15.35	19.33	24.13	29.92
.270	-.224	1.15	2.02	3.59	5.92	7.14	9.50	12.37	15.85	20.08	25.23	31.48
.275	-.226	1.14	2.02	3.61	5.99	7.25	9.69	12.69	16.37	20.87	26.38	33.13
.280	-.228	1.14	2.01	3.62	6.06	7.35	9.89	13.03	16.90	21.68	27.58	34.87
.285	-.230	1.13	2.01	3.63	6.13	7.46	10.09	13.37	17.45	22.52	28.84	36.70
.290	-.232	1.12	2.00	3.64	6.19	7.56	10.29	13.72	18.01	23.40	30.15	38.62
.295	-.233	1.10	1.99	3.66	6.26	7.67	10.50	14.07	18.59	24.30	31.52	40.64
.300	-.235	1.09	1.98	3.66	6.32	7.77	10.70	14.43	19.19	25.24	32.95	42.77

TABLE B1. FREQUENCY FACTORS FOR WESTERN WASHINGTON

KAPPA DISTRIBUTION h= -0.10

τ_3	2 YR	10 YR	25 YR	100 YR	STEP 1	STEP 2	STEP 3	STEP 4	STEP 5	STEP 6	STEP 7	STEP 8
.300	-.235	1.09	1.98	3.66	6.32	7.77	10.70	14.43	19.19	25.24	32.95	42.77
.305	-.237	1.08	1.97	3.67	6.39	7.88	10.91	14.80	19.80	26.21	34.44	45.01
.310	-.238	1.07	1.96	3.68	6.45	7.98	11.12	15.17	20.42	27.21	35.99	47.36
.315	-.239	1.06	1.95	3.69	6.51	8.08	11.33	15.55	21.06	28.25	37.61	49.82
.320	-.240	1.05	1.94	3.69	6.57	8.19	11.54	15.94	21.72	29.32	39.30	52.41
.325	-.241	1.04	1.93	3.69	6.62	8.29	11.75	16.33	22.39	30.42	41.05	55.12
.330	-.242	1.02	1.92	3.69	6.68	8.38	11.96	16.72	23.08	31.55	42.87	57.96
.335	-.243	1.01	1.90	3.69	6.73	8.48	12.16	17.12	23.77	32.73	44.76	60.93
.340	-.244	1.00	1.89	3.69	6.78	8.57	12.37	17.52	24.49	33.93	46.72	64.04
.345	-.244	.98	1.88	3.69	6.83	8.67	12.58	17.92	25.21	35.17	48.75	67.29
.350	-.244	.97	1.86	3.69	6.88	8.75	12.79	18.33	25.95	36.44	50.85	70.68
.355	-.245	.96	1.84	3.68	6.92	8.84	12.99	18.74	26.70	37.74	53.03	74.22
.360	-.245	.94	1.83	3.67	6.96	8.92	13.19	19.14	27.46	39.07	55.28	77.90
.365	-.244	.93	1.81	3.66	7.00	9.00	13.39	19.55	28.23	40.43	57.59	81.74
.370	-.244	.91	1.79	3.65	7.03	9.07	13.58	19.96	29.00	41.82	59.98	85.72
.375	-.244	.90	1.77	3.63	7.06	9.14	13.77	20.36	29.78	43.23	62.44	89.85
.380	-.243	.88	1.75	3.62	7.08	9.21	13.95	20.77	30.57	44.67	64.96	94.14
.385	-.242	.87	1.73	3.60	7.10	9.27	14.12	21.16	31.36	46.13	67.54	98.57
.390	-.241	.85	1.71	3.58	7.12	9.32	14.29	21.55	32.14	47.61	70.19	103.15
.395	-.240	.83	1.68	3.55	7.13	9.37	14.45	21.93	32.93	49.10	72.88	107.86
.400	-.238	.82	1.66	3.53	7.13	9.41	14.61	22.30	33.71	50.60	75.63	112.71

TABLE B2. FREQUENCY FACTORS FOR EASTERN WASHINGTON

KAPPA DISTRIBUTION h= -0.20

$\tau 3$	2 YR	10 YR	25 YR	100 YR	STEP 1	STEP 2	STEP 3	STEP 4	STEP 5	STEP 6	STEP 7	STEP 8
.000	-.005	1.29	1.76	2.32	2.79	2.95	3.17	3.35	3.49	3.60	3.69	3.76
.005	-.010	1.29	1.77	2.34	2.83	3.00	3.23	3.42	3.57	3.69	3.79	3.87
.010	-.015	1.29	1.78	2.37	2.88	3.05	3.30	3.50	3.66	3.79	3.90	3.99
.015	-.020	1.30	1.79	2.39	2.92	3.11	3.37	3.58	3.75	3.90	4.01	4.11
.020	-.025	1.30	1.81	2.42	2.97	3.16	3.44	3.66	3.85	4.00	4.13	4.24
.025	-.029	1.30	1.82	2.44	3.01	3.22	3.51	3.75	3.95	4.12	4.25	4.37
.030	-.034	1.30	1.83	2.47	3.06	3.27	3.58	3.84	4.05	4.23	4.38	4.51
.035	-.039	1.30	1.84	2.50	3.11	3.33	3.65	3.93	4.16	4.35	4.52	4.66
.040	-.044	1.30	1.85	2.52	3.16	3.39	3.73	4.02	4.27	4.48	4.66	4.81
.045	-.049	1.31	1.86	2.55	3.21	3.45	3.81	4.12	4.38	4.61	4.81	4.97
.050	-.054	1.31	1.86	2.58	3.26	3.51	3.89	4.21	4.50	4.74	4.96	5.15
.055	-.059	1.31	1.87	2.60	3.31	3.57	3.97	4.32	4.62	4.89	5.12	5.32
.060	-.064	1.31	1.88	2.63	3.36	3.64	4.05	4.42	4.75	5.03	5.29	5.51
.065	-.068	1.31	1.89	2.66	3.41	3.70	4.14	4.53	4.88	5.19	5.47	5.71
.070	-.073	1.31	1.90	2.68	3.47	3.77	4.23	4.64	5.01	5.35	5.65	5.92
.075	-.078	1.31	1.91	2.71	3.52	3.83	4.32	4.76	5.15	5.52	5.84	6.14
.080	-.082	1.31	1.92	2.74	3.57	3.90	4.41	4.88	5.30	5.69	6.05	6.37
.085	-.087	1.31	1.93	2.76	3.63	3.97	4.51	5.00	5.45	5.87	6.26	6.61
.090	-.092	1.31	1.93	2.79	3.69	4.04	4.60	5.12	5.61	6.06	6.48	6.87
.095	-.096	1.31	1.94	2.82	3.74	4.11	4.70	5.25	5.77	6.26	6.71	7.14
.100	-.101	1.30	1.95	2.84	3.80	4.19	4.80	5.39	5.94	6.46	6.96	7.42

TABLE B2. FREQUENCY FACTORS FOR EASTERN WASHINGTON

KAPPA DISTRIBUTION h= -0.20

$\tau 3$	2 YR	10 YR	25 YR	100 YR	STEP 1	STEP 2	STEP 3	STEP 4	STEP 5	STEP 6	STEP 7	STEP 8
.100	-.101	1.30	1.95	2.84	3.80	4.19	4.80	5.39	5.94	6.46	6.96	7.42
.105	-.105	1.30	1.96	2.87	3.86	4.26	4.91	5.53	6.11	6.68	7.21	7.72
.110	-.110	1.30	1.96	2.90	3.92	4.34	5.02	5.67	6.30	6.90	7.48	8.04
.115	-.114	1.30	1.97	2.92	3.98	4.41	5.12	5.81	6.48	7.13	7.76	8.37
.120	-.118	1.30	1.98	2.95	4.04	4.49	5.24	5.96	6.68	7.37	8.05	8.72
.125	-.123	1.30	1.98	2.98	4.10	4.57	5.35	6.12	6.88	7.63	8.36	9.09
.130	-.127	1.29	1.99	3.00	4.16	4.65	5.47	6.28	7.09	7.89	8.69	9.48
.135	-.131	1.29	1.99	3.03	4.22	4.73	5.59	6.44	7.30	8.16	9.03	9.89
.140	-.135	1.29	2.00	3.05	4.28	4.82	5.71	6.61	7.53	8.45	9.38	10.32
.145	-.139	1.29	2.00	3.08	4.35	4.90	5.84	6.79	7.76	8.75	9.75	10.78
.150	-.143	1.28	2.01	3.10	4.41	4.99	5.96	6.97	8.00	9.06	10.15	11.26
.155	-.147	1.28	2.01	3.13	4.47	5.07	6.09	7.15	8.25	9.38	10.56	11.77
.160	-.151	1.28	2.02	3.15	4.54	5.16	6.23	7.34	8.50	9.72	10.98	12.30
.165	-.155	1.27	2.02	3.18	4.60	5.25	6.36	7.53	8.77	10.07	11.43	12.87
.170	-.159	1.27	2.02	3.20	4.67	5.34	6.50	7.74	9.04	10.43	11.91	13.47
.175	-.163	1.26	2.03	3.23	4.74	5.43	6.64	7.94	9.33	10.81	12.40	14.10
.180	-.167	1.26	2.03	3.25	4.80	5.52	6.79	8.15	9.63	11.21	12.92	14.77
.185	-.170	1.25	2.03	3.28	4.87	5.61	6.94	8.37	9.93	11.63	13.47	15.47
.190	-.174	1.25	2.03	3.30	4.94	5.71	7.09	8.59	10.25	12.06	14.04	16.21
.195	-.177	1.24	2.03	3.32	5.01	5.80	7.24	8.82	10.57	12.51	14.64	16.99
.200	-.181	1.24	2.04	3.34	5.07	5.90	7.40	9.06	10.91	12.97	15.27	17.82

TABLE B2. FREQUENCY FACTORS FOR EASTERN WASHINGTON

KAPPA DISTRIBUTION h= -0.20

τ3	2 YR	10 YR	25 YR	100 YR	STEP 1	STEP 2	STEP 3	STEP 4	STEP 5	STEP 6	STEP 7	STEP 8
.200	-.181	1.24	2.04	3.34	5.07	5.90	7.40	9.06	10.91	12.97	15.27	17.82
.205	-.184	1.23	2.04	3.37	5.14	6.00	7.56	9.30	11.26	13.46	15.92	18.69
.210	-.187	1.23	2.04	3.39	5.21	6.10	7.72	9.55	11.62	13.96	16.61	19.60
.215	-.190	1.22	2.04	3.41	5.28	6.19	7.88	9.81	12.00	14.49	17.33	20.57
.220	-.194	1.21	2.04	3.43	5.35	6.29	8.05	10.07	12.38	15.04	18.09	21.59
.225	-.197	1.21	2.03	3.45	5.42	6.39	8.22	10.33	12.78	15.61	18.88	22.67
.230	-.200	1.20	2.03	3.47	5.49	6.50	8.39	10.61	13.19	16.20	19.71	23.80
.235	-.202	1.19	2.03	3.49	5.55	6.60	8.57	10.89	13.61	16.81	20.58	25.00
.240	-.205	1.19	2.03	3.50	5.62	6.70	8.75	11.18	14.05	17.45	21.48	26.26
.245	-.208	1.18	2.02	3.52	5.69	6.80	8.93	11.47	14.50	18.12	22.43	27.58
.250	-.210	1.17	2.02	3.54	5.76	6.91	9.11	11.77	14.96	18.80	23.42	28.98
.255	-.213	1.16	2.02	3.55	5.83	7.01	9.30	12.08	15.44	19.52	24.46	30.45
.260	-.215	1.15	2.01	3.57	5.90	7.11	9.49	12.39	15.93	20.26	25.54	32.00
.265	-.218	1.14	2.01	3.58	5.96	7.22	9.68	12.71	16.44	21.03	26.68	33.62
.270	-.220	1.13	2.00	3.60	6.03	7.32	9.87	13.04	16.96	21.83	27.86	35.34
.275	-.222	1.12	2.00	3.61	6.09	7.43	10.07	13.37	17.50	22.65	29.09	37.14
.280	-.224	1.11	1.99	3.62	6.16	7.53	10.27	13.71	18.05	23.51	30.38	39.03
.285	-.226	1.10	1.98	3.63	6.22	7.63	10.47	14.06	18.61	24.39	31.72	41.01
.290	-.228	1.09	1.97	3.64	6.29	7.73	10.67	14.41	19.19	25.31	33.12	43.10
.295	-.229	1.08	1.97	3.65	6.35	7.84	10.87	14.77	19.79	26.25	34.57	45.29
.300	-.231	1.07	1.96	3.66	6.41	7.94	11.07	15.13	20.40	27.23	36.09	47.58

TABLE B2. FREQUENCY FACTORS FOR EASTERN WASHINGTON

KAPPA DISTRIBUTION h= -0.20

$\tau 3$	2 YR	10 YR	25 YR	100 YR	STEP 1	STEP 2	STEP 3	STEP 4	STEP 5	STEP 6	STEP 7	STEP 8
.300	-.231	1.07	1.96	3.66	6.41	7.94	11.07	15.13	20.40	27.23	36.09	47.58
.305	-.232	1.06	1.95	3.66	6.47	8.04	11.27	15.50	21.02	28.24	37.67	49.99
.310	-.234	1.05	1.94	3.67	6.53	8.14	11.48	15.87	21.66	29.28	39.31	52.51
.315	-.235	1.04	1.93	3.67	6.58	8.24	11.68	16.25	22.31	30.35	41.01	55.15
.320	-.236	1.03	1.91	3.67	6.64	8.33	11.89	16.63	22.98	31.45	42.78	57.91
.325	-.237	1.01	1.90	3.68	6.69	8.43	12.09	17.02	23.66	32.59	44.61	60.80
.330	-.238	1.00	1.89	3.67	6.74	8.52	12.29	17.41	24.35	33.76	46.51	63.81
.335	-.238	.99	1.87	3.67	6.79	8.61	12.50	17.80	25.05	34.96	48.48	66.96
.340	-.239	.98	1.86	3.67	6.83	8.70	12.70	18.20	25.77	36.19	50.52	70.24
.345	-.239	.96	1.84	3.66	6.88	8.78	12.89	18.60	26.50	37.45	52.63	73.67
.350	-.239	.95	1.83	3.66	6.92	8.86	13.09	18.99	27.23	38.74	54.80	77.23
.355	-.239	.93	1.81	3.65	6.95	8.94	13.28	19.39	27.98	40.06	57.04	80.93
.360	-.239	.92	1.79	3.64	6.99	9.01	13.47	19.79	28.73	41.41	59.35	84.78
.365	-.239	.91	1.77	3.62	7.02	9.08	13.66	20.18	29.49	42.78	61.73	88.76
.370	-.239	.89	1.76	3.61	7.04	9.15	13.84	20.58	30.26	44.17	64.16	92.90
.375	-.238	.87	1.73	3.59	7.07	9.21	14.01	20.96	31.03	45.59	66.66	97.17
.380	-.237	.86	1.71	3.57	7.08	9.27	14.18	21.35	31.79	47.02	69.22	101.58
.385	-.236	.84	1.69	3.55	7.10	9.31	14.34	21.72	32.56	48.47	71.83	106.12
.390	-.235	.83	1.67	3.53	7.10	9.36	14.49	22.09	33.32	49.93	74.48	110.80
.395	-.234	.81	1.64	3.50	7.11	9.39	14.64	22.45	34.07	51.39	77.18	115.59
.400	-.232	.79	1.62	3.47	7.10	9.42	14.77	22.79	34.82	52.86	79.92	120.50

WORKSHEET FOR COMPUTATION OF

PRECIPITATION MAGNITUDE-FREQUENCY CURVE

PROJECT:________________________ FILE NO:________

LOCATION:____________________ North ______ ° West ______ °

CLIMATIC REGION:___ MEAN ANNUAL PRECIPITATION:_______ Inches

DURATION OF INTEREST:______ Hours DESIGN STEP:_____

PARAMETERS FOR COMPUTATION OF AT-SITE MEAN

6 Hour, 2 Year Partial Duration Value (X_6) _______ Inches
24 Hour, 2 Year Partial Duration Value (X_{24}) _______ Inches
Regional Value of Coefficient of Variation (C_v) _______
Regional Value of L-Skewness (τ_3) _______
Frequency Factor for 2 Year Event (K_2) _______

Latitude Index (L_1) _______
Longitude Index (L_2) _______
Elevation Index (Z) _______

2 Year Partial Duration Value X_{2p} = _______ Inches

At-Site Mean $\overline{X}$ = _______ Inches

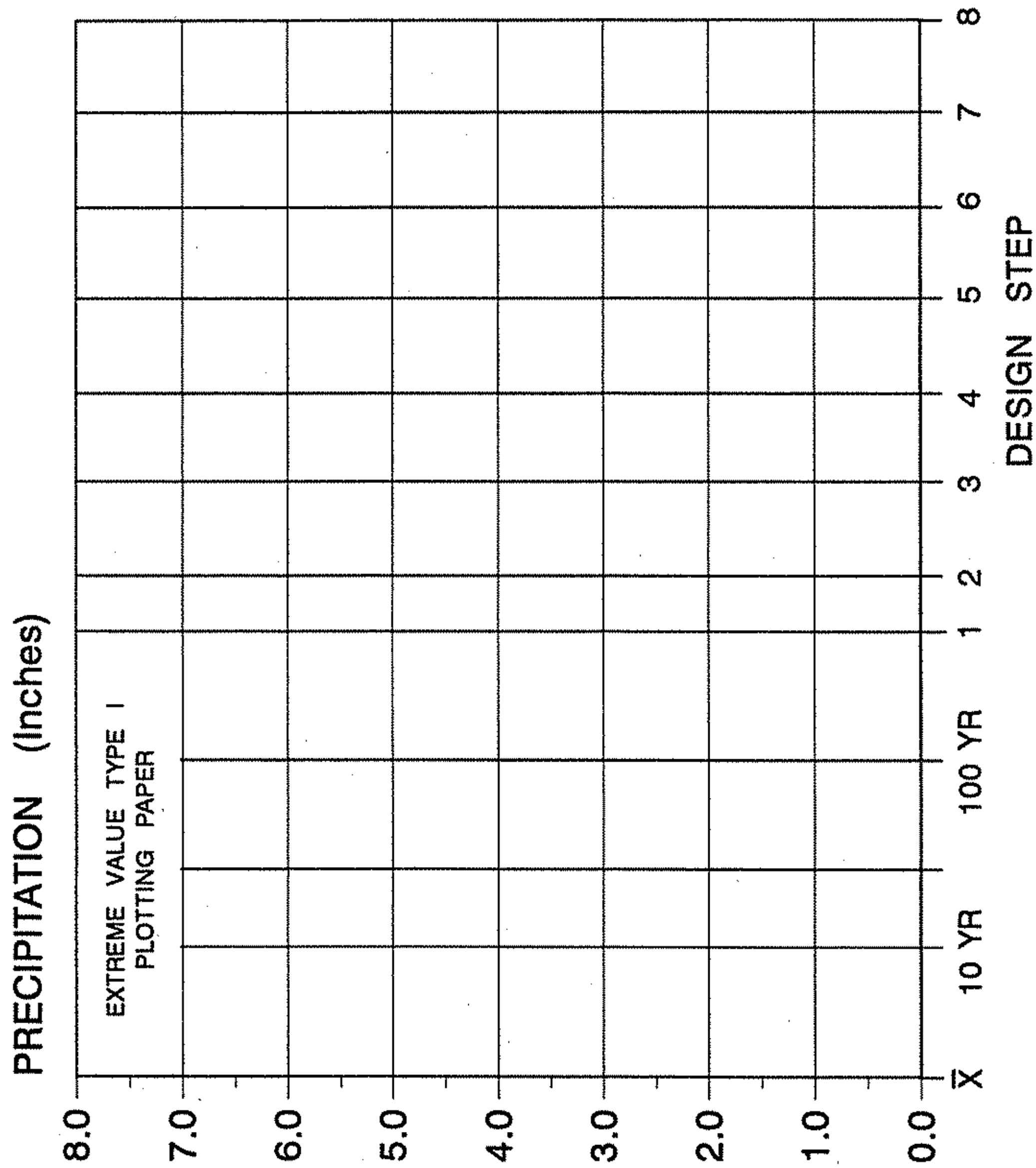
$$\overline{X} = \frac{.88X_{2p}}{(1 + K_2C_v)}$$

FREQUENCY	2 YR	10 YR	25 YR	100 YR	500 YR	STEP 2	STEP 3	STEP 4	STEP 5	STEP 6	STEP 7	STEP 8
FREQUENCY FACTORS												
QUANTILE ESTIMATES (Inches)												

$$X_i = \overline{X}(1 + K_iC_v)$$

___ HOUR DESIGN PRECIPITATION P_d = _______ Inches - Design Step ___

$$P_d = 1.15\overline{X}(1 + K_{ds}C_v)$$


PRECIPITATION (Inches)
EXTREME VALUE TYPE I
PLOTTING PAPER
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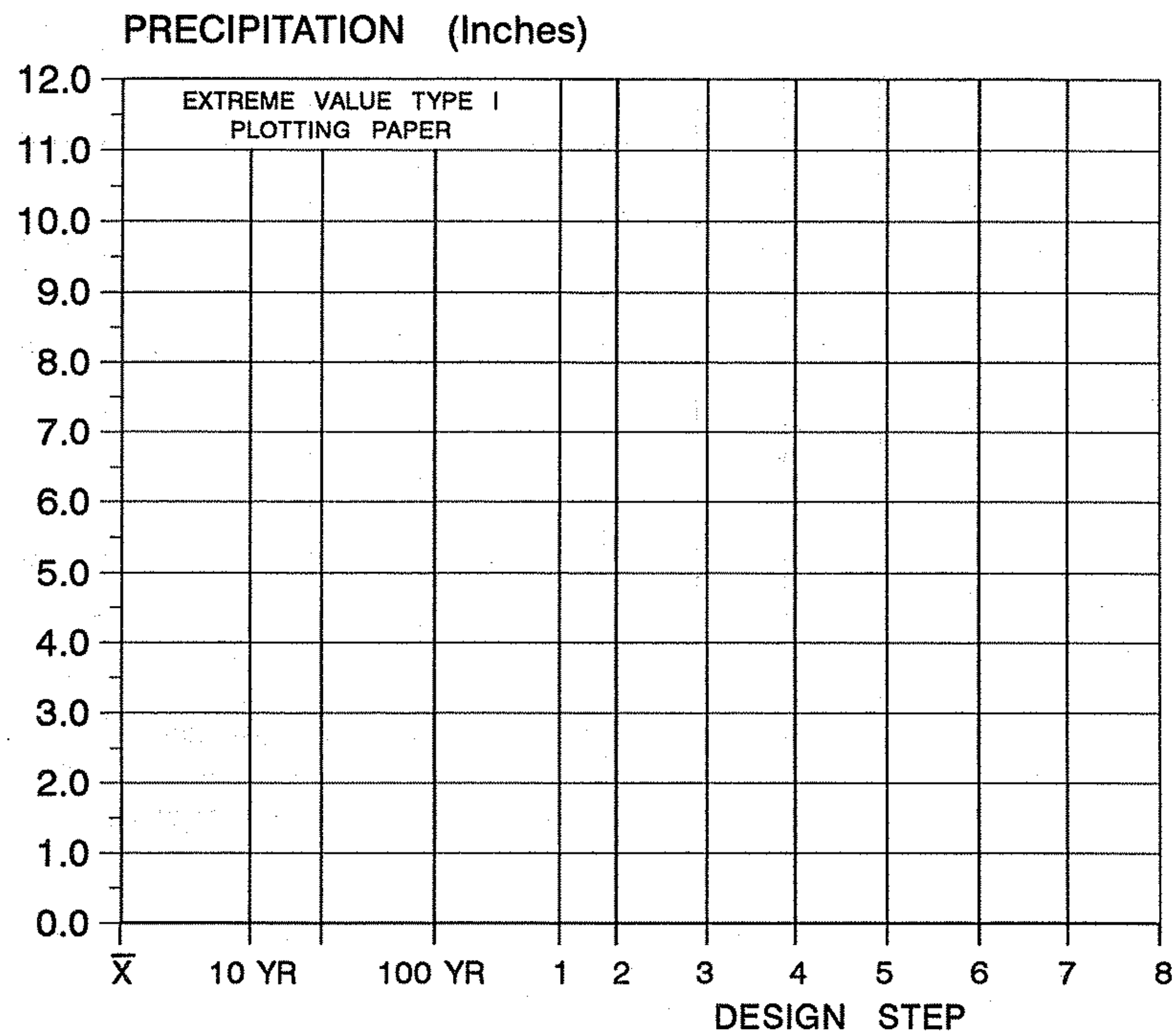
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
X̄
10 YR
100 YR
1
2
3
4
5
6
7
8
DESIGN STEP


PRECIPITATION (Inches)
EXTREME VALUE TYPE I
PLOTTING PAPER
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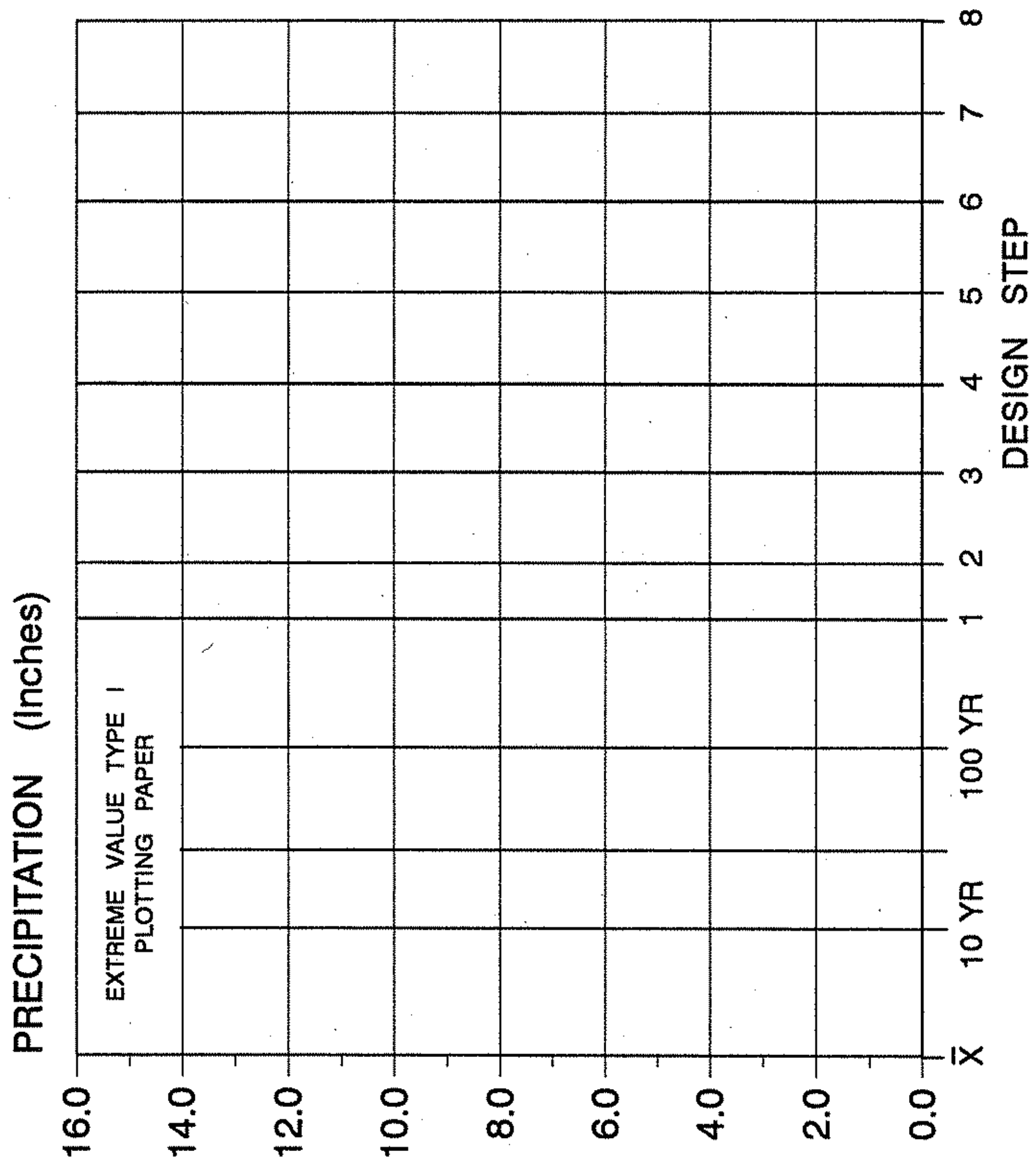
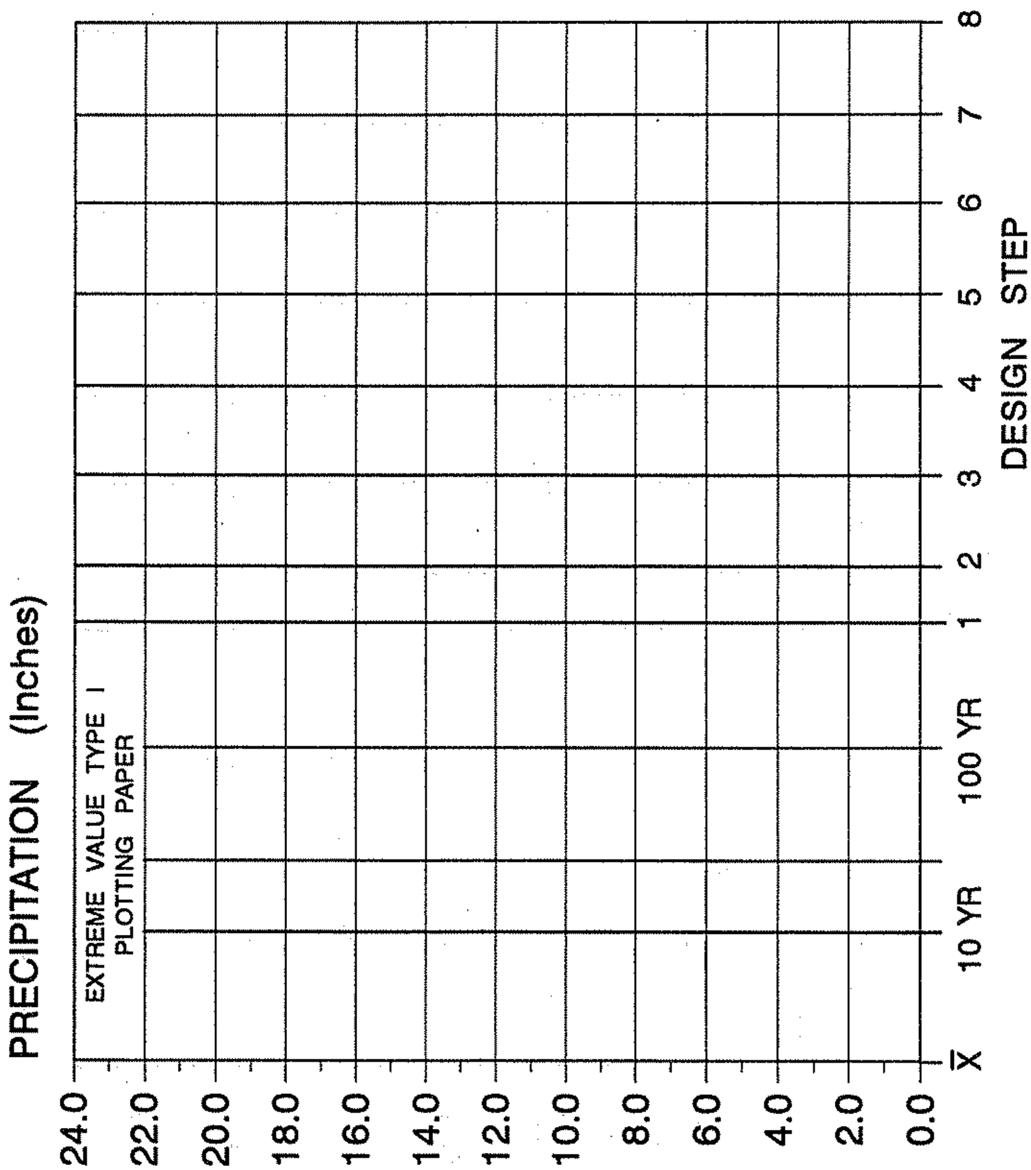
11.0
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
$\overline{X}$
10 YR
100 YR
1
2
3
4
5
6
7
8
DESIGN STEP


PRECIPITATION (Inches)
EXTREME VALUE TYPE I
PLOTTING PAPER
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
X̄
10 YR
100 YR
1
2
3
4
5
6
7
8
DESIGN STEP


PRECIPITATION (Inches)
EXTREME VALUE TYPE I
PLOTTING PAPER
24.0
22.0
20.0
18.0
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
X̄
10 YR
100 YR
1
2
3
4
5
6
7
8
DESIGN STEP

APPENDIX C

DESIGN HYETOGRAPHS FOR SMALL WATERSHEDS

TABLE C1a. REGION 1 - SHORT DURATION DESIGN HYETOGRAPH

File M02-33.R01 - INCREMENTAL PRECIPITATION AMOUNTS - 5 Minute Values

PI	.0058	.0092	.0160	.0220	.0260	.0280	.0300	.0569	.1561	.2970
PI	.2020	.1370	.0400	.0030	.0025	.0020	.0018	.0017	.0016	.0016
PI	.0016	.0016	.0016	.0016	.0016	.0016	.0016	.0016	.0016	.0016
PI	.0016	.0015	.0014	.0013	.0012	.0011	.0010	.0010	.0010	.0010
PI	.0008	.0007	.0006	.0006	.0005	.0005	.0005	.0001	.0001	.0001
PI	.0001	.0001	.0001	.0001	.0001	.0001	.0001	.0001	.0001	.0001
PI	.0001	.0001	.0001	.0001	.0001	.0001	.0001	.0001	.0001	.0001
PI	.0001	.0001								

TABLE C1b. REGION 1 - INTERMEDIATE DURATION DESIGN HYETOGRAPH

File M06-20.R01 - INCREMENTAL PRECIPITATION AMOUNTS - 15 Minute Values

PI	.0032	.0032	.0033	.0033	.0034	.0035	.0036	.0037	.0039	.0041
PI	.0042	.0044	.0047	.0049	.0051	.0053	.0055	.0057	.0060	.0062
PI	.0064	.0066	.0068	.0070	.0072	.0079	.0091	.0108	.0130	.0157
PI	.0189	.0226	.0265	.0297	.0317	.0328	.0425	.0998	.1590	.0710
PI	.0451	.0453	.0446	.0428	.0402	.0376	.0350	.0325	.0302	.0279
PI	.0258	.0237	.0218	.0199	.0182	.0165	.0150	.0137	.0125	.0115
PI	.0107	.0100	.0094	.0088	.0083	.0078	.0074	.0071	.0068	.0066
PI	.0065	.0065								

TABLE C1c. REGION 1 - LONG DURATION DESIGN HYETOGRAPH

File M24-20I.R01 - INCREMENTAL PRECIPITATION AMOUNTS - 30 Minute Values

PI	.0019	.0019	.0019	.0019	.0019	.0019	.0019	.0019	.0020	.0020
PI	.0020	.0020	.0020	.0021	.0021	.0021	.0022	.0022	.0022	.0023
PI	.0023	.0024	.0024	.0024	.0025	.0025	.0026	.0026	.0027	.0027
PI	.0028	.0028	.0028	.0029	.0029	.0029	.0030	.0030	.0030	.0031
PI	.0031	.0031	.0031	.0031	.0032	.0032	.0032	.0032	.0033	.0034
PI	.0037	.0042	.0048	.0056	.0065	.0076	.0088	.0101	.0117	.0133
PI	.0146	.0156	.0162	.0169	.0176	.0181	.0185	.0189	.0194	.0206
PI	.0223	.0246	.0281	.0359	.0433	.0530	.0970	.0470	.0410	.0390
PI	.0350	.0333	.0294	.0264	.0240	.0219	.0199	.0181	.0164	.0149
PI	.0136	.0124	.0114	.0105	.0098	.0092	.0088	.0084	.0080	.0076
PI	.0073	.0070	.0067	.0064	.0061	.0059	.0056	.0054	.0052	.0050
PI	.0049	.0047	.0045	.0044	.0042	.0041	.0039	.0038	.0037	.0036
PI	.0034	.0033	.0032	.0031	.0030	.0029	.0029	.0028	.0027	.0026
PI	.0026	.0025	.0024	.0024	.0023	.0023	.0023	.0022	.0022	.0022
PI	.0022	.0021	.0021	.0021						

TABLE C1d. REGION 1 - LONG DURATION DESIGN HYETOGRAPH

File M24-20V.R01 - INCREMENTAL PRECIPITATION AMOUNTS - 30 Minute Values

PI	.0034	.0034	.0034	.0035	.0035	.0036	.0036	.0037	.0038	.0039
PI	.0040	.0041	.0042	.0044	.0045	.0046	.0047	.0049	.0050	.0051
PI	.0052	.0054	.0055	.0056	.0057	.0059	.0060	.0061	.0062	.0064
PI	.0065	.0066	.0067	.0068	.0070	.0071	.0072	.0073	.0075	.0076
PI	.0078	.0080	.0082	.0084	.0086	.0088	.0090	.0092	.0095	.0098
PI	.0100	.0103	.0106	.0109	.0112	.0115	.0119	.0122	.0126	.0129
PI	.0133	.0137	.0142	.0147	.0152	.0158	.0165	.0172	.0179	.0187
PI	.0195	.0203	.0212	.0223	.0235	.0249	.0294	.0486	.0690	.0460
PI	.0401	.0369	.0294	.0246	.0235	.0230	.0225	.0218	.0210	.0201
PI	.0192	.0182	.0173	.0165	.0157	.0150	.0143	.0137	.0130	.0124
PI	.0118	.0112	.0106	.0101	.0095	.0090	.0085	.0080	.0075	.0070
PI	.0066	.0062	.0058	.0054	.0051	.0048	.0045	.0042	.0040	.0038
PI	.0036	.0034	.0032	.0031	.0029	.0028	.0026	.0025	.0024	.0022
PI	.0021	.0020	.0019	.0018	.0018	.0017	.0016	.0016	.0015	.0015
PI	.0015	.0014	.0014	.0014						

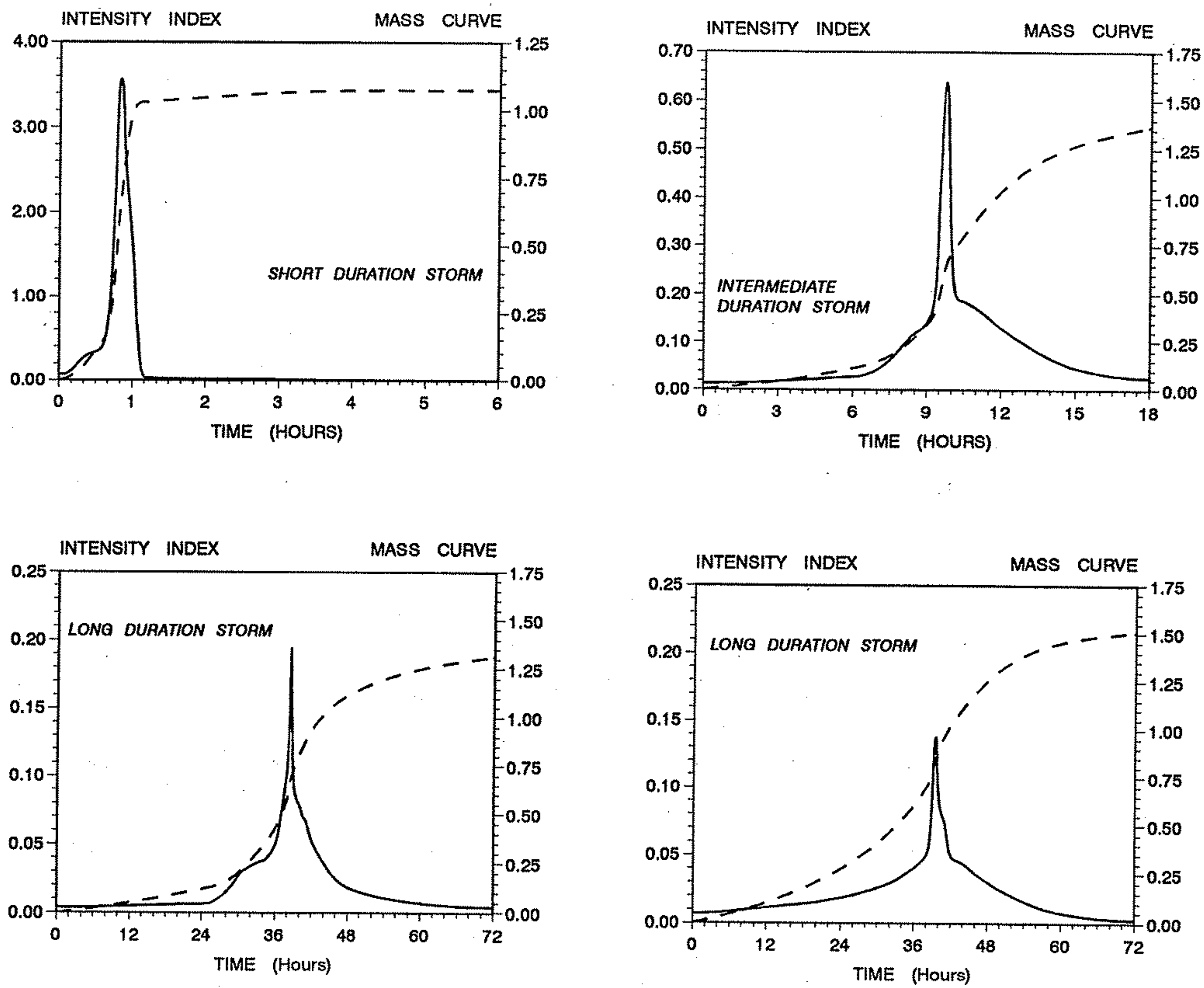


FIGURE C1. DESIGN HYETOGRAPHS FOR REGION 1 - MOUNTAINOUS AREAS OF EASTERN WASHINGTON

TABLE C2a. REGION 2 - SHORT DURATION DESIGN HYETOGRAPH

File M02-33.R02 - INCREMENTAL PRECIPITATION AMOUNTS - 5 Minute Values

PI	.0058	.0092	.0160	.0220	.0260	.0280	.0300	.0569	.1561	.2970
PI	.2020	.1370	.0400	.0030	.0025	.0020	.0018	.0017	.0016	.0016
PI	.0016	.0016	.0016	.0016	.0016	.0016	.0016	.0016	.0016	.0016
PI	.0016	.0015	.0014	.0013	.0012	.0011	.0010	.0010	.0010	.0010
PI	.0008	.0007	.0006	.0006	.0005	.0005	.0005	.0001	.0001	.0001
PI	.0001	.0001	.0001	.0001	.0001	.0001	.0001	.0001	.0001	.0001
PI	.0001	.0001	.0001	.0001	.0001	.0001	.0001	.0001	.0001	.0001
PI	.0001	.0001								

TABLE C2b. REGION 2 - INTERMEDIATE DURATION DESIGN HYETOGRAPH

File M06-20.R02 - INCREMENTAL PRECIPITATION AMOUNTS - 15 Minute Values

PI	.0027	.0027	.0027	.0027	.0027	.0027	.0027	.0027	.0027	.0027
PI	.0027	.0027	.0027	.0027	.0027	.0028	.0028	.0029	.0030	.0032
PI	.0033	.0034	.0036	.0038	.0041	.0049	.0063	.0083	.0109	.0140
PI	.0173	.0208	.0245	.0284	.0325	.0366	.0417	.0990	.1590	.0710
PI	.0455	.0430	.0418	.0404	.0389	.0372	.0354	.0335	.0316	.0296
PI	.0275	.0253	.0232	.0209	.0186	.0162	.0138	.0117	.0100	.0088
PI	.0078	.0070	.0062	.0056	.0050	.0045	.0040	.0036	.0033	.0031
PI	.0030	.0029								

TABLE C2c. REGION 2 - LONG DURATION DESIGN HYETOGRAPH

File M24-20I.R02 - INCREMENTAL PRECIPITATION AMOUNTS - 30 Minute Values

PI	.0002	.0002	.0002	.0002	.0002	.0002	.0002	.0003	.0003	.0003
PI	.0003	.0003	.0004	.0004	.0004	.0005	.0005	.0005	.0006	.0006
PI	.0007	.0007	.0008	.0008	.0009	.0011	.0015	.0021	.0029	.0038
PI	.0049	.0061	.0076	.0092	.0110	.0129	.0149	.0167	.0181	.0192
PI	.0199	.0202	.0203	.0207	.0216	.0229	.0246	.0268	.0302	.0378
PI	.0410	.0485	.0640	.1240	.0475	.0430	.0410	.0364	.0309	.0261
PI	.0221	.0186	.0156	.0131	.0111	.0095	.0084	.0075	.0068	.0062
PI	.0057	.0054	.0053	.0051	.0050	.0049	.0047	.0046	.0044	.0043
PI	.0041	.0040	.0039	.0037	.0036	.0034	.0033	.0031	.0030	.0029
PI	.0027	.0026	.0025	.0024	.0023	.0022	.0021	.0020	.0019	.0018
PI	.0017	.0016	.0016	.0015	.0014	.0014	.0013	.0012	.0012	.0011
PI	.0011	.0010	.0010	.0009	.0009	.0009	.0009	.0008	.0008	.0008
PI	.0008	.0008	.0007	.0007	.0007	.0007	.0007	.0007	.0007	.0007
PI	.0007	.0007	.0006	.0006	.0006	.0006	.0006	.0006	.0006	.0006
PI	.0006	.0006	.0006	.0006						

TABLE C2d. REGION 2 - LONG DURATION DESIGN HYETOGRAPH

File M24-20V.R02 - INCREMENTAL PRECIPITATION AMOUNTS - 30 Minute Values

PI	.0020	.0020	.0020	.0020	.0020	.0020	.0020	.0020	.0020	.0020
PI	.0020	.0021	.0021	.0021	.0021	.0021	.0021	.0021	.0021	.0022
PI	.0022	.0022	.0022	.0022	.0023	.0023	.0023	.0024	.0024	.0025
PI	.0025	.0026	.0027	.0028	.0029	.0030	.0031	.0032	.0034	.0038
PI	.0046	.0057	.0071	.0088	.0109	.0133	.0160	.0190	.0224	.0261
PI	.0309	.0401	.0610	.0930	.0602	.0320	.0309	.0299	.0290	.0281
PI	.0272	.0263	.0254	.0245	.0236	.0229	.0222	.0215	.0209	.0202
PI	.0194	.0185	.0175	.0164	.0153	.0141	.0131	.0121	.0112	.0104
PI	.0096	.0089	.0083	.0078	.0073	.0069	.0066	.0063	.0060	.0058
PI	.0055	.0053	.0050	.0048	.0046	.0044	.0042	.0041	.0039	.0038
PI	.0036	.0035	.0034	.0033	.0033	.0032	.0032	.0031	.0031	.0031
PI	.0031	.0031	.0031	.0031	.0031	.0031	.0030	.0030	.0030	.0030
PI	.0029	.0029	.0028	.0028	.0027	.0027	.0026	.0025	.0024	.0024
PI	.0023	.0022	.0021	.0020	.0019	.0018	.0017	.0017	.0016	.0016
PI	.0015	.0015	.0015	.0015						

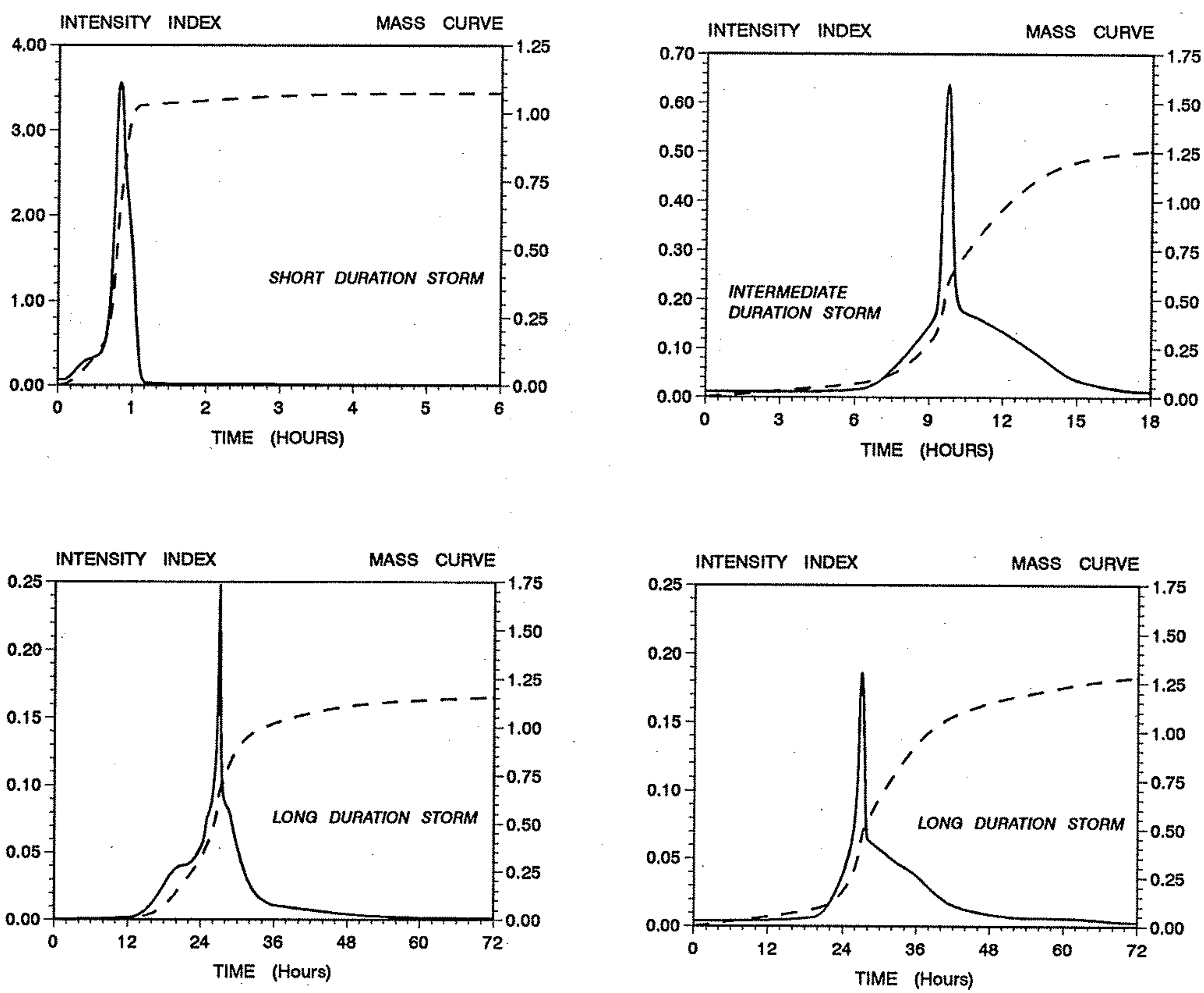


FIGURE C2. DESIGN HYETOGRAPHS FOR REGION 2 - CENTRAL BASIN AREA OF EASTERN WASHINGTON

TABLE C3a. REGION 3 - SHORT DURATION DESIGN HYETOGRAPH

File M02-33.R03 - INCREMENTAL PRECIPITATION AMOUNTS - 5 Minute Values

PI	.0064	.0069	.0078	.0092	.0111	.0135	.0161	.0180	.0189	.0204
PI	.0283	.0633	.1380	.1550	.1490	.1091	.0716	.0482	.0366	.0278
PI	.0195	.0090	.0085	.0077	.0073	.0068	.0066	.0064	.0063	.0062
PI	.0061	.0059	.0053	.0048	.0044	.0041	.0038	.0036	.0034	.0032
PI	.0031	.0030	.0029	.0028	.0028	.0028	.0028	.0028	.0029	.0030
PI	.0030	.0031	.0031	.0031	.0031	.0032	.0032	.0031	.0031	.0031
PI	.0031	.0030	.0030	.0030	.0029	.0029	.0029	.0029	.0029	.0028
PI	.0028	.0028								

TABLE C3b. REGION 3 - INTERMEDIATE DURATION DESIGN HYETOGRAPH

File M06-20.R03 - INCREMENTAL PRECIPITATION AMOUNTS - 15 Minute Values

PI	.0031	.0031	.0032	.0032	.0032	.0033	.0034	.0035	.0036	.0037
PI	.0038	.0040	.0041	.0043	.0046	.0048	.0052	.0055	.0060	.0064
PI	.0069	.0075	.0081	.0087	.0094	.0101	.0109	.0117	.0126	.0135
PI	.0145	.0155	.0165	.0177	.0188	.0200	.0213	.0225	.0238	.0250
PI	.0262	.0275	.0287	.0299	.0310	.0322	.0334	.0345	.0357	.0368
PI	.0378	.0388	.0630	.1390	.0815	.0315	.0305	.0295	.0285	.0275
PI	.0264	.0234	.0208	.0184	.0164	.0146	.0131	.0119	.0109	.0101
PI	.0096	.0094								

TABLE C3c. REGION 3 - LONG DURATION DESIGN HYETOGRAPH

File M24-20I.R03 - INCREMENTAL PRECIPITATION AMOUNTS - 30 Minute Values

PI	.0001	.0001	.0001	.0001	.0002	.0002	.0002	.0002	.0002	.0003
PI	.0003	.0003	.0004	.0004	.0004	.0005	.0005	.0006	.0006	.0007
PI	.0008	.0008	.0009	.0010	.0010	.0011	.0012	.0014	.0015	.0016
PI	.0018	.0020	.0022	.0024	.0026	.0029	.0032	.0034	.0037	.0041
PI	.0044	.0047	.0051	.0055	.0059	.0063	.0067	.0072	.0076	.0081
PI	.0085	.0090	.0094	.0098	.0103	.0107	.0111	.0115	.0120	.0124
PI	.0128	.0135	.0144	.0155	.0169	.0185	.0204	.0222	.0238	.0254
PI	.0269	.0280	.0290	.0300	.0310	.0320	.0710	.0430	.0386	.0351
PI	.0320	.0295	.0276	.0259	.0249	.0238	.0227	.0214	.0199	.0183
PI	.0167	.0151	.0137	.0125	.0114	.0105	.0097	.0090	.0083	.0076
PI	.0069	.0063	.0057	.0052	.0047	.0042	.0038	.0033	.0030	.0026
PI	.0023	.0020	.0017	.0015	.0013	.0012	.0010	.0009	.0009	.0009
PI	.0008	.0008	.0008	.0008	.0008	.0008	.0008	.0008	.0008	.0008
PI	.0008	.0008	.0008	.0008	.0008	.0008	.0008	.0007	.0007	.0007
PI	.0007	.0007	.0007	.0007						

TABLE C3d. REGION 3 - LONG DURATION DESIGN HYETOGRAPH

File M24-20V.R03 - INCREMENTAL PRECIPITATION AMOUNTS - 30 Minute Values

PI	.0017	.0017	.0017	.0017	.0017	.0017	.0018	.0018	.0018	.0018
PI	.0018	.0018	.0018	.0018	.0018	.0018	.0018	.0018	.0018	.0018
PI	.0019	.0019	.0019	.0019	.0019	.0019	.0020	.0020	.0021	.0022
PI	.0023	.0025	.0026	.0028	.0029	.0031	.0033	.0035	.0038	.0040
PI	.0043	.0046	.0049	.0052	.0056	.0060	.0064	.0068	.0073	.0079
PI	.0086	.0094	.0103	.0114	.0125	.0135	.0144	.0152	.0159	.0164
PI	.0169	.0173	.0178	.0183	.0187	.0192	.0197	.0202	.0208	.0214
PI	.0223	.0234	.0247	.0262	.0284	.0320	.0600	.0390	.0335	.0322
PI	.0309	.0296	.0283	.0270	.0257	.0244	.0231	.0220	.0209	.0200
PI	.0190	.0180	.0164	.0147	.0130	.0112	.0094	.0079	.0067	.0058
PI	.0052	.0049	.0049	.0049	.0049	.0049	.0048	.0048	.0048	.0047
PI	.0047	.0046	.0046	.0045	.0044	.0043	.0042	.0041	.0040	.0039
PI	.0038	.0036	.0035	.0034	.0033	.0032	.0031	.0030	.0029	.0028
PI	.0028	.0027	.0026	.0026	.0025	.0025	.0024	.0024	.0024	.0023
PI	.0023	.0023	.0023	.0023						

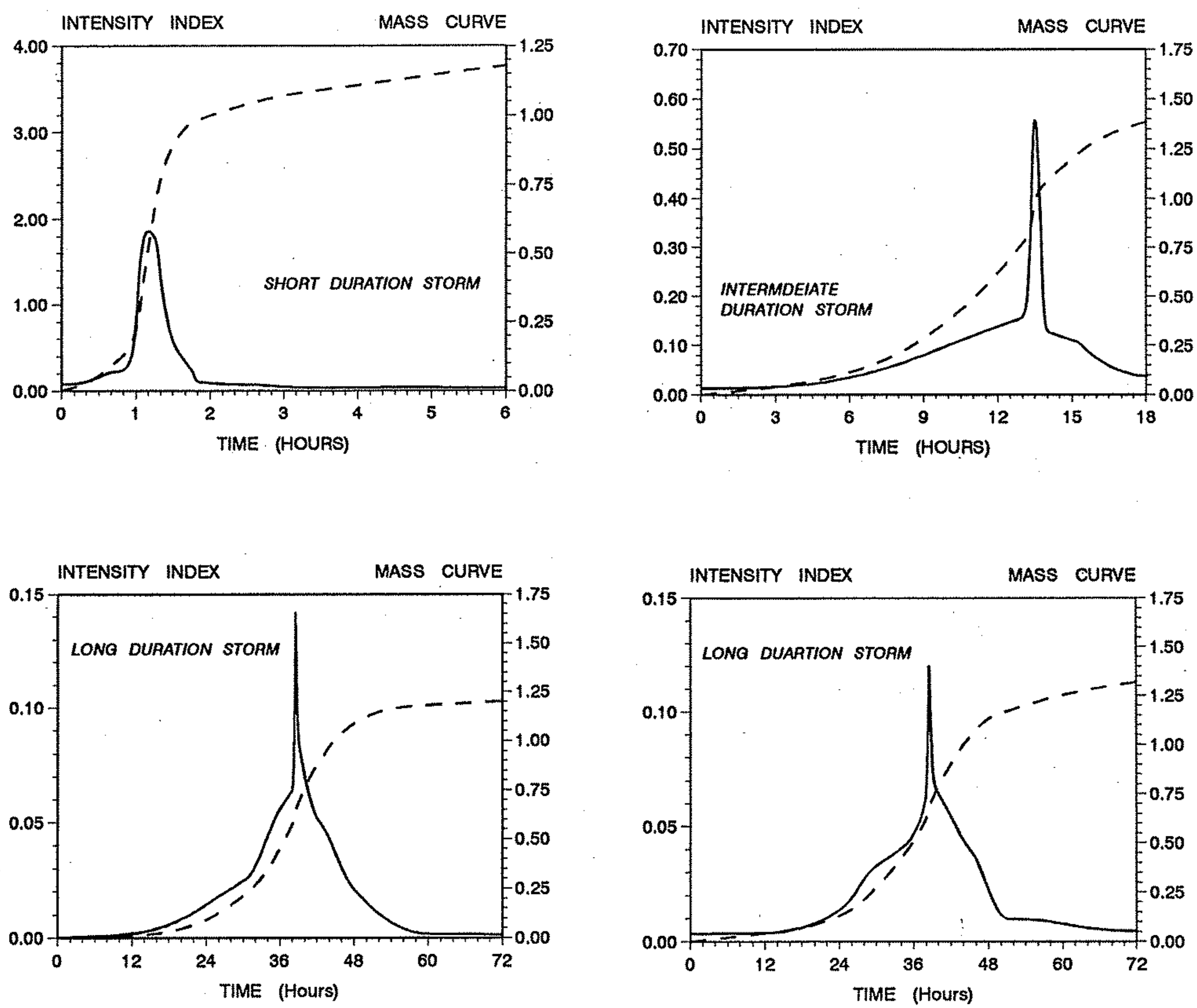


FIGURE C3. DESIGN HYETOGRAPHS FOR REGION 3 - PUGET SOUND LOWLANDS IN WESTERN WASHINGTON

TABLE C4a. REGION 4 - SHORT DURATION DESIGN HYETOGRAPH

File M02-33.R04 - INCREMENTAL PRECIPITATION AMOUNTS - 5 Minute Values

PI	.0064	.0069	.0078	.0092	.0111	.0135	.0161	.0180	.0189	.0204
PI	.0283	.0633	.1380	.1550	.1490	.1091	.0716	.0482	.0366	.0278
PI	.0195	.0090	.0085	.0077	.0073	.0068	.0066	.0064	.0063	.0062
PI	.0061	.0059	.0053	.0048	.0044	.0041	.0038	.0036	.0034	.0032
PI	.0031	.0030	.0029	.0028	.0028	.0028	.0028	.0028	.0029	.0030
PI	.0030	.0031	.0031	.0031	.0031	.0032	.0032	.0031	.0031	.0031
PI	.0031	.0030	.0030	.0030	.0029	.0029	.0029	.0029	.0029	.0028
PI	.0028	.0028								

TABLE C4b. REGION 4 - INTERMEDIATE DURATION DESIGN HYETOGRAPH

File M06-20.R04 - INCREMENTAL PRECIPITATION AMOUNTS - 15 Minute Values

PI	.0066	.0066	.0067	.0067	.0067	.0067	.0067	.0068	.0068	.0068
PI	.0069	.0069	.0070	.0071	.0073	.0075	.0077	.0080	.0083	.0087
PI	.0091	.0096	.0101	.0107	.0113	.0118	.0123	.0127	.0131	.0134
PI	.0136	.0138	.0139	.0140	.0140	.0139	.0139	.0140	.0145	.0152
PI	.0162	.0175	.0191	.0209	.0230	.0255	.0282	.0311	.0342	.0367
PI	.0385	.0395	.0630	.1390	.0878	.0445	.0413	.0403	.0393	.0382
PI	.0369	.0354	.0339	.0322	.0307	.0294	.0283	.0273	.0266	.0260
PI	.0256	.0255								

TABLE C4c. REGION 4 - LONG DURATION DESIGN HYETOGRAPH

File M24-20I.R04 - INCREMENTAL PRECIPITATION AMOUNTS - 30 Minute Values

PI	.0055	.0055	.0055	.0055	.0055	.0055	.0055	.0055	.0055	.0056
PI	.0056	.0056	.0056	.0056	.0056	.0057	.0057	.0057	.0057	.0058
PI	.0058	.0058	.0058	.0059	.0059	.0060	.0060	.0061	.0061	.0062
PI	.0062	.0063	.0064	.0065	.0066	.0067	.0068	.0069	.0070	.0071
PI	.0072	.0073	.0074	.0074	.0075	.0076	.0076	.0077	.0077	.0078
PI	.0078	.0078	.0078	.0078	.0078	.0080	.0083	.0088	.0095	.0104
PI	.0114	.0123	.0133	.0141	.0149	.0156	.0162	.0168	.0174	.0179
PI	.0184	.0188	.0192	.0196	.0199	.0202	.0205	.0207	.0209	.0212
PI	.0215	.0218	.0221	.0225	.0229	.0235	.0243	.0254	.0266	.0281
PI	.0298	.0315	.0340	.0490	.0350	.0220	.0198	.0190	.0186	.0183
PI	.0180	.0177	.0175	.0173	.0171	.0169	.0167	.0165	.0163	.0161
PI	.0159	.0157	.0155	.0153	.0150	.0145	.0139	.0133	.0127	.0119
PI	.0111	.0104	.0096	.0089	.0082	.0076	.0070	.0064	.0059	.0054
PI	.0049	.0045	.0041	.0037	.0034	.0031	.0028	.0026	.0024	.0022
PI	.0021	.0020	.0019	.0019						

TABLE C4d. REGION 4 - LONG DURATION DESIGN HYETOGRAPH

File M24-20V.R04 - INCREMENTAL PRECIPITATION AMOUNTS - 30 Minute Values

PI	.0055	.0055	.0055	.0055	.0055	.0055	.0055	.0055	.0055	.0056
PI	.0056	.0056	.0056	.0056	.0056	.0057	.0057	.0057	.0057	.0058
PI	.0058	.0058	.0058	.0059	.0059	.0060	.0060	.0061	.0061	.0062
PI	.0062	.0063	.0064	.0065	.0066	.0067	.0068	.0069	.0070	.0071
PI	.0072	.0073	.0074	.0074	.0075	.0076	.0076	.0077	.0077	.0078
PI	.0078	.0078	.0078	.0078	.0078	.0080	.0083	.0088	.0095	.0104
PI	.0114	.0123	.0133	.0141	.0149	.0156	.0162	.0168	.0174	.0179
PI	.0184	.0188	.0192	.0196	.0199	.0202	.0205	.0207	.0209	.0212
PI	.0215	.0218	.0221	.0225	.0229	.0235	.0243	.0254	.0266	.0281
PI	.0298	.0315	.0340	.0490	.0350	.0220	.0198	.0190	.0186	.0183
PI	.0180	.0177	.0175	.0173	.0171	.0169	.0167	.0165	.0163	.0161
PI	.0159	.0157	.0155	.0153	.0150	.0145	.0139	.0133	.0127	.0119
PI	.0111	.0104	.0096	.0089	.0082	.0076	.0070	.0064	.0059	.0054
PI	.0049	.0045	.0041	.0037	.0034	.0031	.0028	.0026	.0024	.0022
PI	.0021	.0020	.0019	.0019						

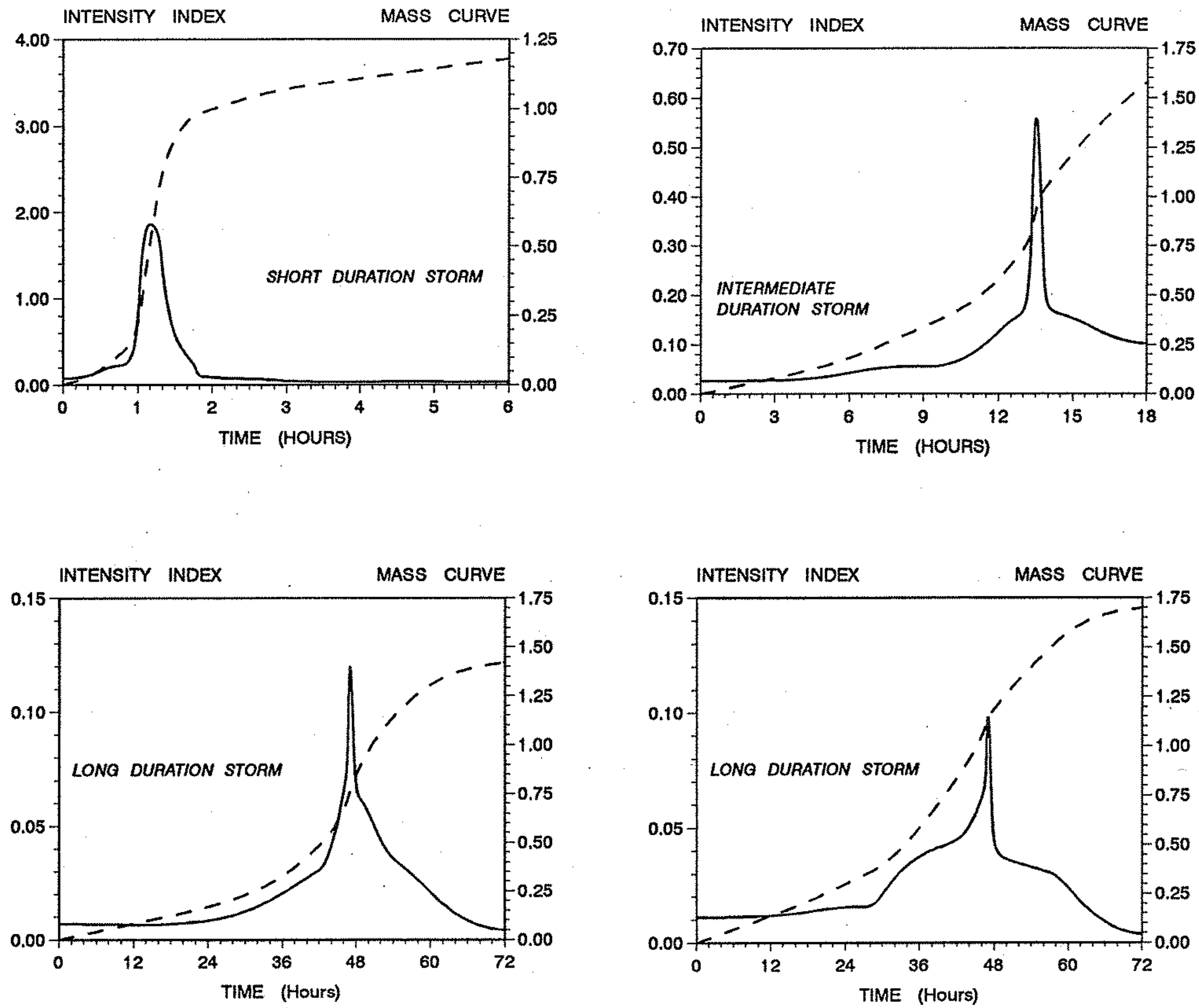


FIGURE C4. DESIGN HYETOGRAPHS FOR REGION 4 - MOUNTAINOUS AREAS OF WESTERN WASHINGTON

TABLE C5a. REGION 5 - SHORT DURATION DESIGN HYETOGRAPH

File M02-33.R05 - INCREMENTAL PRECIPITATION AMOUNTS - 5 Minute Values

PI	.0064	.0069	.0078	.0092	.0111	.0135	.0161	.0180	.0189	.0204
PI	.0283	.0633	.1380	.1550	.1490	.1091	.0716	.0482	.0366	.0278
PI	.0195	.0090	.0085	.0077	.0073	.0068	.0066	.0064	.0063	.0062
PI	.0061	.0059	.0053	.0048	.0044	.0041	.0038	.0036	.0034	.0032
PI	.0031	.0030	.0029	.0028	.0028	.0028	.0028	.0028	.0029	.0030
PI	.0030	.0031	.0031	.0031	.0031	.0032	.0032	.0031	.0031	.0031
PI	.0031	.0030	.0030	.0030	.0029	.0029	.0029	.0029	.0029	.0028
PI	.0028	.0028								

TABLE C5b. REGION 5 - INTERMEDIATE DURATION DESIGN HYETOGRAPH

File M06-20.R05 - INCREMENTAL PRECIPITATION AMOUNTS - 15 Minute Values

PI	.0048	.0048	.0048	.0049	.0049	.0050	.0051	.0051	.0052	.0053
PI	.0054	.0056	.0057	.0059	.0061	.0063	.0066	.0068	.0072	.0075
PI	.0079	.0083	.0087	.0092	.0096	.0100	.0104	.0107	.0109	.0111
PI	.0112	.0112	.0112	.0111	.0109	.0107	.0105	.0105	.0109	.0117
PI	.0127	.0142	.0160	.0181	.0206	.0234	.0265	.0300	.0337	.0366
PI	.0387	.0400	.0630	.1390	.0961	.0519	.0436	.0423	.0406	.0385
PI	.0363	.0341	.0322	.0304	.0288	.0274	.0263	.0253	.0245	.0239
PI	.0235	.0233								

TABLE C5c. REGION 5 - LONG DURATION DESIGN HYETOGRAPH

File M24-20I.R05 - INCREMENTAL PRECIPITATION AMOUNTS - 30 Minute Values

PI	.0024	.0024	.0024	.0024	.0024	.0024	.0024	.0024	.0024	.0024
PI	.0024	.0024	.0024	.0024	.0024	.0024	.0024	.0024	.0024	.0024
PI	.0024	.0024	.0024	.0025	.0025	.0025	.0025	.0025	.0025	.0026
PI	.0026	.0026	.0027	.0027	.0028	.0028	.0029	.0029	.0030	.0031
PI	.0032	.0033	.0033	.0034	.0035	.0036	.0037	.0039	.0040	.0042
PI	.0046	.0050	.0056	.0063	.0071	.0079	.0086	.0092	.0098	.0103
PI	.0107	.0111	.0114	.0116	.0118	.0119	.0119	.0122	.0125	.0131
PI	.0139	.0148	.0159	.0172	.0187	.0203	.0217	.0233	.0247	.0259
PI	.0271	.0283	.0296	.0310	.0326	.0346	.0390	.0650	.0491	.0321
PI	.0269	.0244	.0223	.0206	.0192	.0183	.0176	.0171	.0165	.0161
PI	.0156	.0152	.0149	.0144	.0139	.0133	.0125	.0117	.0108	.0098
PI	.0087	.0075	.0065	.0055	.0047	.0040	.0035	.0030	.0027	.0025
PI	.0024	.0024	.0023	.0022	.0022	.0021	.0021	.0020	.0020	.0019
PI	.0019	.0019	.0018	.0018	.0018	.0017	.0017	.0017	.0017	.0017
PI	.0017	.0017	.0017	.0016						

TABLE C5d. REGION 5 - LONG DURATION DESIGN HYETOGRAPH

File M24-20V.R05 - INCREMENTAL PRECIPITATION AMOUNTS - 30 Minute Values

PI	.0033	.0033	.0033	.0033	.0033	.0033	.0033	.0033	.0033	.0033
PI	.0033	.0033	.0033	.0033	.0032	.0032	.0032	.0032	.0032	.0032
PI	.0032	.0032	.0032	.0032	.0032	.0032	.0032	.0032	.0033	.0034
PI	.0034	.0035	.0036	.0038	.0039	.0040	.0042	.0044	.0046	.0048
PI	.0050	.0052	.0055	.0057	.0060	.0063	.0066	.0069	.0073	.0078
PI	.0084	.0093	.0102	.0111	.0119	.0126	.0133	.0138	.0143	.0146
PI	.0149	.0151	.0153	.0155	.0157	.0159	.0161	.0163	.0165	.0168
PI	.0175	.0183	.0193	.0205	.0217	.0231	.0246	.0257	.0266	.0274
PI	.0282	.0290	.0298	.0306	.0314	.0322	.0360	.0540	.0484	.0373
PI	.0285	.0219	.0176	.0171	.0166	.0161	.0156	.0151	.0148	.0144
PI	.0139	.0135	.0130	.0126	.0121	.0117	.0112	.0108	.0104	.0100
PI	.0096	.0093	.0089	.0085	.0082	.0079	.0075	.0072	.0069	.0066
PI	.0063	.0060	.0058	.0055	.0053	.0050	.0048	.0046	.0044	.0042
PI	.0040	.0039	.0037	.0036	.0034	.0033	.0032	.0031	.0031	.0030
PI	.0029	.0029	.0029	.0029						

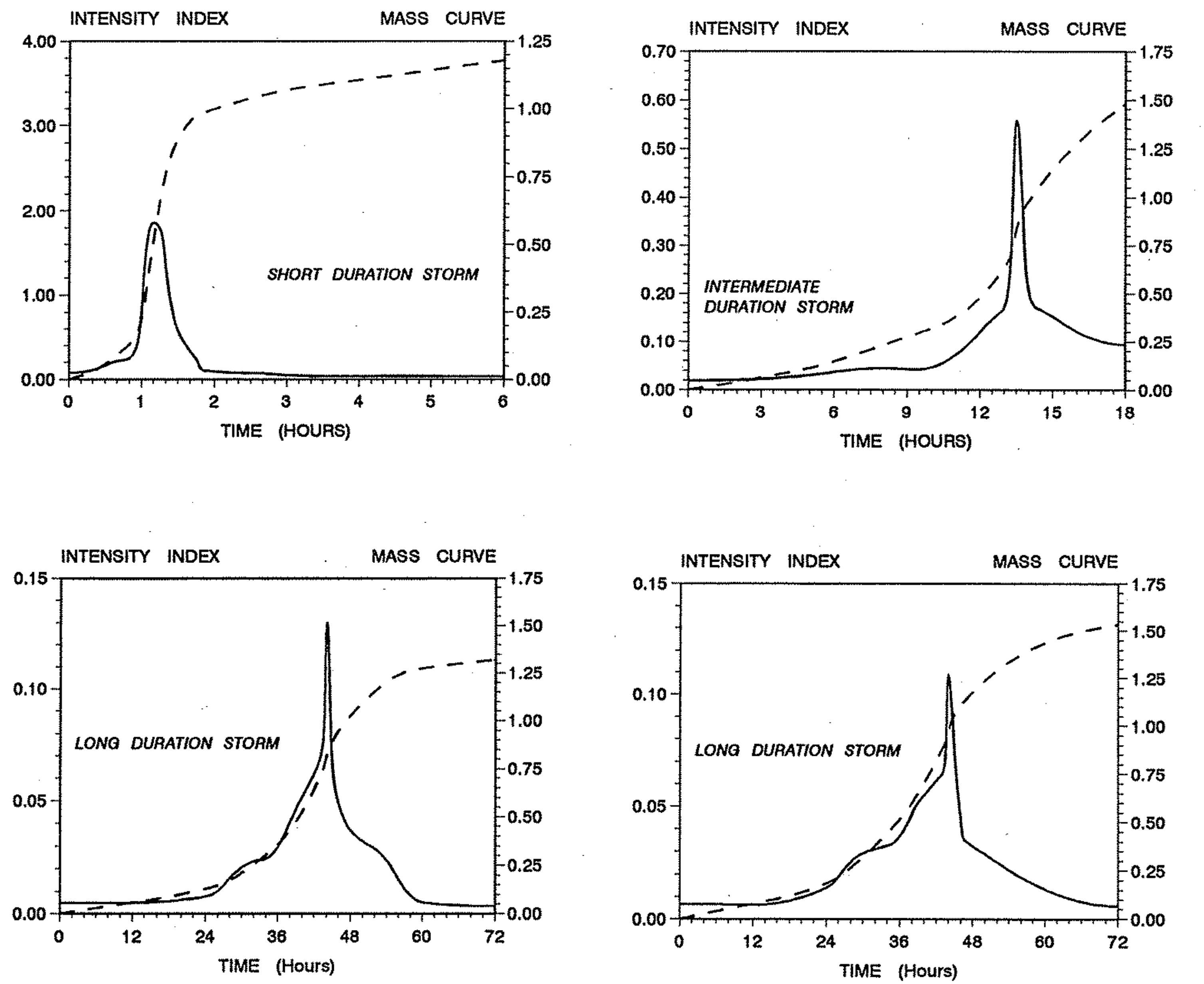


FIGURE C5. DESIGN HYETOGRAPHS FOR REGION 5 - COASTAL LOWLANDS OF WESTERN WASHINGTON

APPENDIX D

EXAMPLES OF HYETOGRAPH CONSTRUCTION

D1. EXAMPLES OF HYETOGRAPH CONSTRUCTION

The following examples present the procedures used to construct candidate design storms for small and large watersheds.

D1.1 EXAMPLE D1

Construct an intermediate duration design storm hyetograph for a small watershed at a project site near Everett, WA.

GIVEN: Project site at 48.00°N 123.00°W with a tributary watershed of 5 mi^2.
Mean Annual Precipitation (MAP) is 43 inches and Design Step 3.

DECISION: Basin less than 10 mi^2 - no corrections for areal distribution are required

INFORMATION: Refer to Figure 1 for the computational steps to be used.

6 hr, 2 yr partial duration value from NOAA Atlas 2, X_6 = 1.04 inches
Regional value of Coefficient of Variation from Figure 5a, C_v = 0.265
Regional value of L-Skewness from Figure 6a, τ_3 = 0.180
Frequency Factor for 2 yr event from Appendix B, Table B1, K_2 = -0.169
Climatic Region 3 - Puget Sound Lowlands

At-Site Mean X = 0.965 inches, Equation 2

FREQUENCY	2 YR	10 YR	25 YR	100 YR	500 YR	STEP 2	STEP 3	STEP 4	STEP 5	STEP 6	STEP 7	STEP 8
FREQUENCY FACTORS	-.169	1.28	2.04	3.22	4.67	5.32	6.45	7.63	8.87	10.17	11.54	12.97
QUANTILE ESTIMATES (inches)	0.92	1.29	1.49	1.79	2.16	2.33	2.61	2.92	3.23	3.57	3.92	4.28

$$X_i = \overline{X}\,(1 + K_i C_v)$$

6 Hour Design Precipitation P_d = 3.00 Inches - Design Step 3, from equation 12

Figure D1.1 depicts the computed magnitude-frequency curve. Figure D1.2 depicts the hyetograph obtained by multiplying the dimensionless ordinates of the intermediate duration hyetograph for Region 3 contained in Appendix C by the 6 hour design precipitation of 3.00 inches.

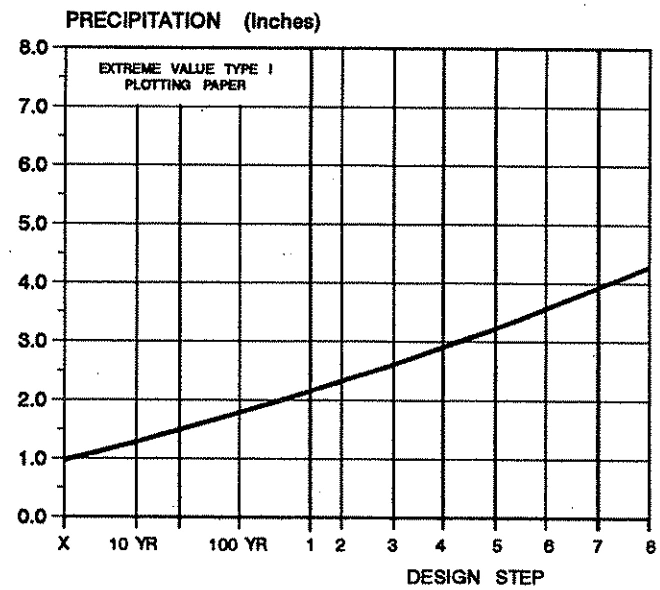


FIGURE D1.1 EXAMPLE D1 - PRECIPITATION MAGNITUDE-FREQUENCY CURVE

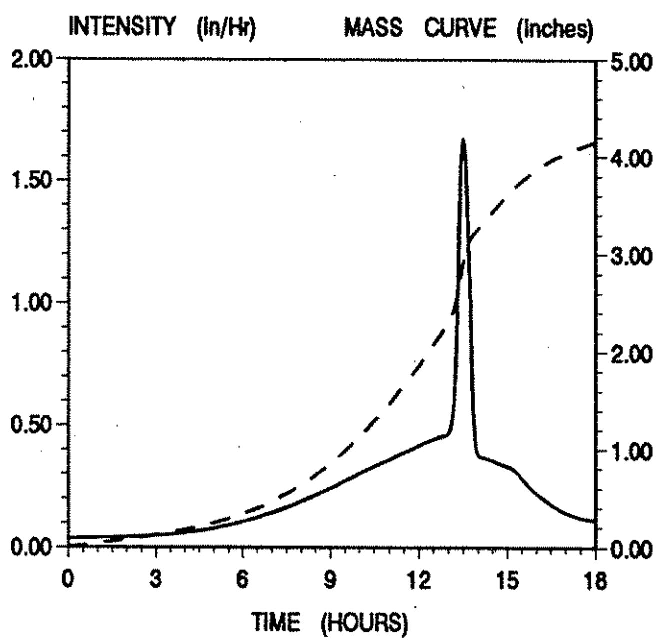


FIGURE D1.2 EXAMPLE D1 - INTERMEDIATE DURATION HYETOGRAPH

D1.2 EXAMPLE D2

Construct a short duration design storm hyetograph for a large watershed on Hunters Creek at a project site near Hunters, WA. in the Selkirk Mountains.

GIVEN: Center of 38 mi^2 tributary watershed for project site is at 48.15°N 118.15°W. Mean Annual Precipitation (MAP) is 20 inches, Mean Elevation in watershed is 3300 feet and Design Step 5.

DECISION: Review of Figures A1, A4 and regional parameters C_v and τ_3 indicate that neither the at-site mean nor the design precipitation will vary significantly across the watershed. Therefore, computation of the design precipitation for the geographical center of the watershed will be adequate. This simplified procedure will be used in lieu of placing a grid over the watershed and computing a design precipitation at the nodes for use in determining the weighted average design precipitation.

INFORMATION: Refer to Figure 2 for the computational steps to be used.

6 hr, 2 yr partial duration value from NOAA Atlas 2, X_6 = 0.80 inches
24 hr, 2 yr partial duration value from NOAA Atlas 2, X_{24} = 1.40 inches
Mean Watershed Elevation, Z = 33 (Elevation in hundreds of feet)
Climatic Region 1 - Mountainous Areas of Eastern Washington

2 Hour Partial Duration Amount X_{2p} = 0.485 inches, Equation 5

Regional value of Coefficient of Variation from Figure 5a, C_v = 0.405
Regional value of L-Skewness from Figure 6a, τ_3 = 0.275
Frequency Factor for 2 yr event from Appendix B, Table B2, K_2 = -0.222

At-Site Mean $\overline{X}$ = 0.470 inches, Equation 2

FREQUENCY	2 YR	10 YR	25 YR	100 YR	500 YR	STEP 2	STEP 3	STEP 4	STEP 5	STEP 6	STEP 7	STEP 8
FREQUENCY FACTORS	-.222	1.12	2.00	3.61	6.09	7.43	10.07	13.37	17.50	22.65	29.09	37.14
QUANTILE ESTIMATES (inches)	0.43	0.68	0.85	1.16	1.63	1.88	2.39	3.01	3.80	4.78	6.01	7.54

$$X_i = \overline{X} (1 + K_i C_v)$$

2 Hour Design Precipitation P_d = 4.37 Inches - Design Step 5, from equation 12

Figure D2.1 depicts the computed magnitude-frequency curve for the geographical center of the project watershed. It should be noted that this is an at-site curve representative of 1 mi^2 areal coverage. Adjustments of the selected depth-duration curve will be accomplished next to account for attenuation of the storm from the storm center. These adjustments will be incorporated during construction of the design hyetograph.

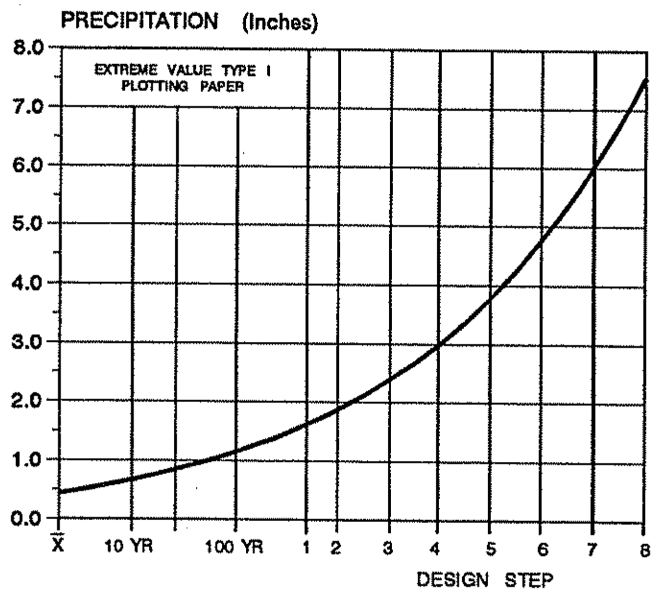


FIGURE D2.1 EXAMPLE D2 - PRECIPITATION MAGNITUDE-FREQUENCY CURVE

DEPTH-DURATION CURVE: The next step in constructing the design hyetograph is to select the depth-duration curve and to make adjustments to account for the spatial distribution of the storm.

In accordance with Table 3 recommendations, a depth-duration curve with an exceedance probability of 33% is selected (page 42 of *Characteristics of Extreme Precipitation Events in Washington State*[3]).

Adjust the dimensionless ordinates of the depth-duration curve by the factors depicted in Figure 16 corresponding to 38 mi^2, (page 70 of *Characteristics of Extreme Precipitation Events in Washington State*[3]).

This is shown in the Table below.

TABLE D2.1 DEPTH-DURATION CURVE ORDINATES

DIMENSIONLESS DEPTH - DURATION CURVE ORDINATES			
INTERDURATIONS	ORIGINAL ORDINATES	AREAL ADJUSTMENTS	FINAL ORDINATES
0.08 Hours	0.297	0.45	0.134
0.17 Hours	0.499	0.45	0.225
0.25 Hours	0.636	0.45	0.286
0.50 Hours	0.882	0.50	0.441
0.75 Hours	0.969	0.54	0.523
1.00 Hours	1.000	0.58	0.580
1.25 Hours	1.000	0.59	0.590
1.50 Hours	1.000	0.60	0.600
2.00 Hours	1.000	0.62	0.620
3.00 Hours	1.015	0.65	0.660
4.00 Hours	1.027	0.68	0.698
5.00 Hours	1.037	0.69	0.716
6.00 Hours	1.044	0.70	0.731

The adjusted dimensionless ordinates can now be scaled by the 2 hour design precipitation of 4.37 inches to produce a depth-duration curve for the 38 mi^2 watershed. The incremental precipitation amounts in the depth-duration curve can now be rearranged to construct the design hyetograph. Before proceeding with that step, the various storm characteristics must be specified. Consistent with recommendations in Table 3 of this technical note, the following characteristics are specified:

Exceedance Probability of Selected Storm Characteristics = 33%
Time of Occurrence of High Intensity Storm Segment = 0.80 Hours, (Table 10[3])
Sequence of Occurrence of High Intensity Storm Segments = 213, (Table 11[3])
Macro Storm Pattern = Type I (Figure 6d[3])
Macro Storm Sequence = 123456 (Figure 6d,Figure 5[3])

The following Tables present the scaled depth-duration curve and the incremental precipitation amounts, and the design hyetograph constructed in accordance with the characteristics specified above.

TABLES D2.3 DEPTH-DURATION CURVE AND DESIGN HYETOGRAPHS

TIME (Hours)	DEPTH-DURATION CURVE (Inches)
0.08	0.59
0.17	0.98
0.25	1.25
0.50	1.93
0.75	2.29
1.00	2.53
1.25	2.58
1.50	2.62
2.00	2.71
3.00	2.88
4.00	3.05
5.00	3.13
6.00	3.19

TIME INCREMENT (Hours)	INCREMENTAL PRECIPITATION (Inches)
0.083	0.59
0.083	0.39
0.083	0.27
0.25	0.68
0.25	0.36
0.25	0.24
0.25	0.05
0.25	0.04
0.50	0.09
1.00	0.17
1.00	0.17
1.00	0.08
1.00	0.06

TIME (Hours)	MASS HYETOGRAPH (Inches)	INCREMENTAL AMOUNTS (Inches)	INTENSITY HYETOGRAPH (Inches/Hour)
0.00	0.00		
0.25	0.04	0.04	0.16
0.50	0.40	0.36	1.44
0.67	0.86	0.46	2.76
0.75	1.25	0.39	4.68
0.83	1.84	0.59	7.08
0.92	2.11	0.27	3.24
1.00	2.33	0.22	2.64
1.25	2.57	0.24	0.96
1.50	2.62	0.05	0.20
2.00	2.71	0.09	0.18
3.00	2.88	0.17	0.17
4.00	3.05	0.17	0.17
5.00	3.13	0.08	0.08
6.00	3.19	0.06	0.06

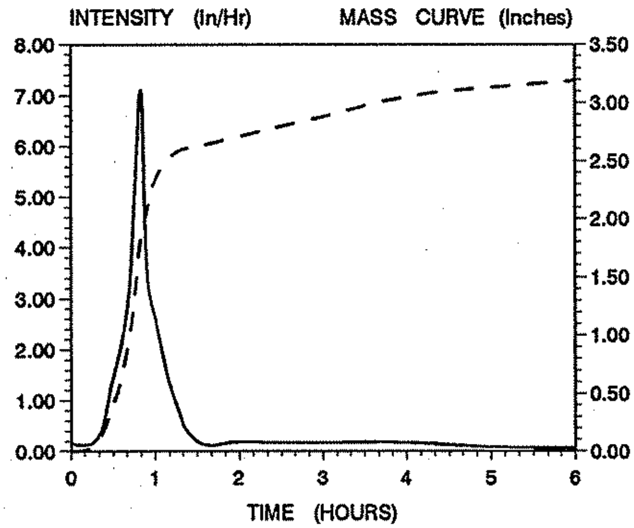


FIGURE D2.2 EXAMPLE D2 - SHORT DURATION HYETOGRAPH